Testing and Evaluation of Automotive Propane Conversion Equipment: 2

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ABSTRACT

A series of tests has been carried out on a FORD 4.9 L (300 CID) I6 engine model BF 251 AB, with respect to the optimization of selected principles of propane carburetion systems (IMPCO, BEAM, A.F.S.), using as criteria performance of the engine, fuel economy and emissions. Results indicate that output power is equal to the power developed using gasoline and the fuel energy efficiency is improved by 3.8 to 17.8% for the best systems. Taking into account the 45% increase of volume for propane at an equivalent weight, this results in an increase of 13.4 to 32.7% of volumetric consumption. Through optimization of air-fuel ratio and timing, a further improvement of efficiency from 5.8 to 9.1% was achieved. The exhaust gas temperatures are comparable with those encountered for gasoline, if the timing and air-fuel ratio are correct. Hydrocarbons and carbon monoxide emissions are lower and nitric oxide emission higher than for gasoline (measured before catalytic converter).

1. INTRODUCTION

The Ministry of Transportation and Communications for the Province of Ontario (MTC) has contracted with the Engine Research and Development Laboratory of the Department of Mechanical Engineering, University of Toronto (ERDL/UTME), to undertake a long range investigation of the use of propane as an alternative fuel in internal combustion engines. The work to date has been directed specifically towards the evaluation of various propane conversion systems on a variety of engines, typifying the spectrum of light and medium weight road vehicles.

The present investigation is the fourth in a series of evaluations. It was carried out on a 4.9 L, 6 cylinder Ford light truck engine, a type which enjoys widespread use. Three basically different carburetion systems were used. The objectives were to assess relative performance of these systems and to perform an optimization with respect to fuel economy and engine performance.

2. EXPERIMENTAL FACILITIES

2.1 TEST ENGINE

Make: FORD, Cleveland Engine Plant 1

Identification: BF 251 AB, code E

Number of cylinders: 6, in line, OHV

Serial number: C-00207-H-23-TG

Bore: 4.00 in. (101.600 mm)

Stroke: 3.98 in. (101.092 mm)

Displacement: 4.9 L (300 CID)

Compression Ratio: 8.6:1

Camshaft: 'standard' 1981 (Overlap 48°; intake opens 18°BTC, duration 268°; exhaust opens 58°BBC, duration 268°; lift 0.40 in.)

Carburettor: CARTER E1TE DA

← A1E 15 NON2

choke: EB 1672A

Distributor: 1F23

E1TE 12127 JA OPT

Spark plugs: BSF 42 MOTORCRAFT

gap: 0.045 in.

Firing order: 153624

Emissions control system: calibration 1-51G as in 1981 F-100/150 vehicles - see Fig. 2-1. The original catalytic converter and muffler are installed.

EGR valve: E1TE-9D 448-H2A 776
1E12AE

Air pump: COT E1TE-D2A

Electrical system: designed for engine dynomometer testing - see Fig. 2-2

Generator: 40A E1ZF 10346 AA

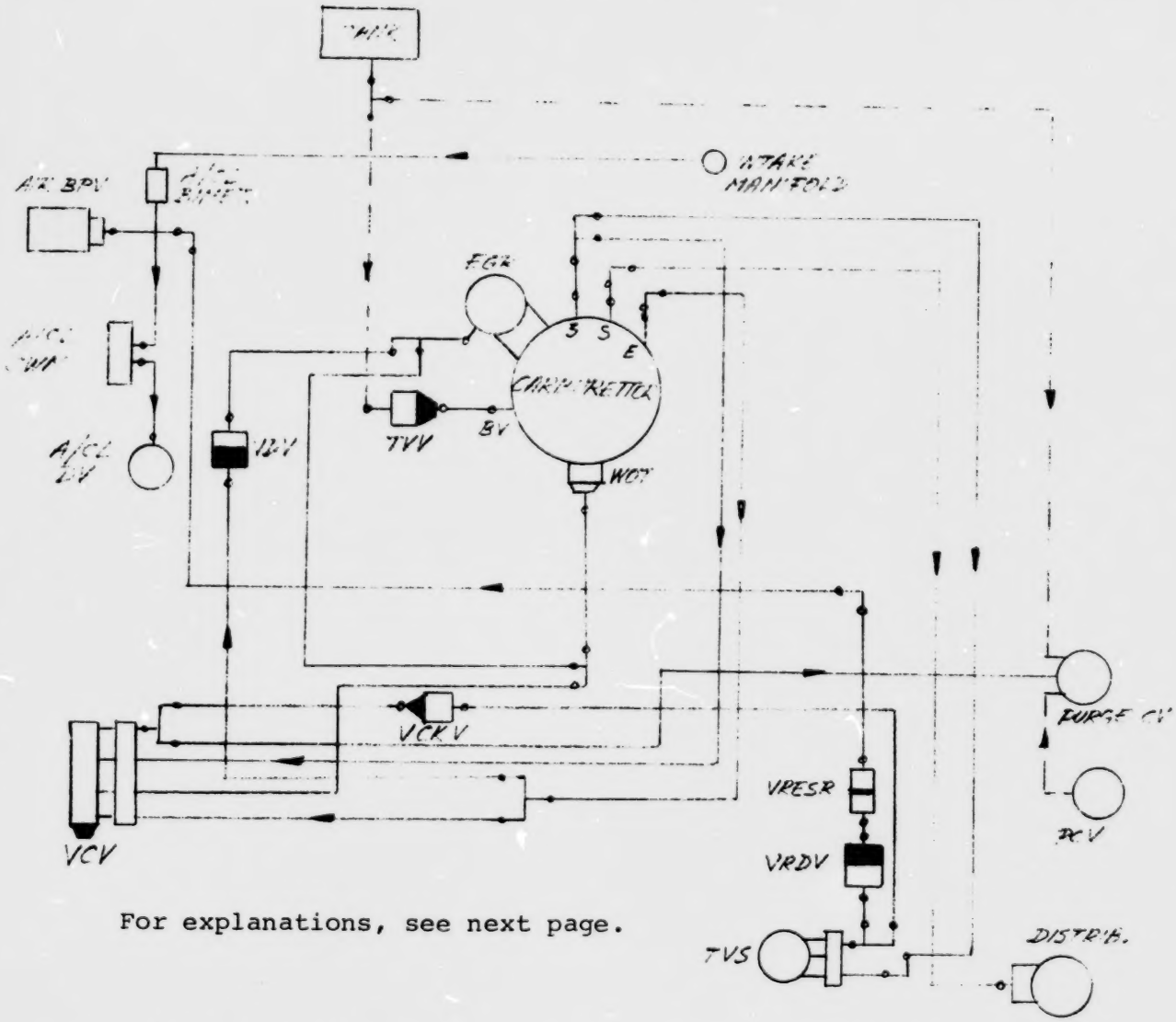
Voltage regulator: D9PF-10316-AB NEG

Electronic module: DURASPARK D8VE 12A199A2C

Fan: fixed blades, H D20E-AB

Dynamometer coupling: standard flywheel, clutch and bellhousing for manual transmission

Engine support: 3 points (2 for engine, 1 for dynomometer, with original rubber vibration dampers), ensuring the horizontal position of the carburettor mounting surface on the intake manifold



For explanations, see next page.

Figure 2-1: Emissions control system for gasoline

Fig. 2-1: Emissions control system for gasoline (cont'd)

TVS = temperature vacuum switch
BPV = bypass valve
VRDV = vacuum retard delay valve
VCV = vacuum control valve
VCKV = vacuum check valve
VDV = vacuum differential delay valve
TVV = thermal vent valve
WOT = wide open throttle valve
VRESER = vacuum reservoir
A/CL = air cleaner
DV = duct and valve vacuum motor
CWM = cold weather modulator
EGR = exhaust recirculation valve
PCV = positive crank case ventilation valve

Inlet Air Temperature Control System: the aircleaner intake duct has a door controlled by a vacuum motor (A/CL DV), admitting cold air from outside or preheated air from a heat shroud around the exhaust manifold. The bimetal (A/CL BIMET.) and cold weather modulator (A/CL CWM) control the air temperature at which the vacuum is supplied to A/CL DV to activate the door for heated air.

Thermactor Air Injection System: reduces the hydrocarbon and carbon monoxide content of exhaust by continuing the combustion in the exhaust manifold through injection of fresh air. The air is supplied by a mechanically driven

pump and a check valve. At idle, the vacuum control of the bypass valve (AIR BPV) is routing the air supply out to atmosphere.

Evaporative Emission System: the fuel vapors from fuel tank and carburetter are stored into a carbon canister and under control of canister purge valve (PURGE CV) are drawn into the engine and burned.

Exhaust Gas Recirculation System: the vacuum controlled EGR valve reintroduces small amounts of exhaust gas into the combustion chamber, reducing the NO_x emission. At or near WOT, the EGR vacuum load control valve (WOT) is venting the EGR vacuum to atmosphere.

Vacuum Control Valve (VCV): controls vacuum during warm-up. It opens two separate circuits of vacuum when engine coolant reaches the calibration temperature.

Temperature Vacuum Switch (TVS): same as VCV, bimetal activated.

Vacuum Delay Valve (VDV, VRDV): used for gradual application or release of vacuum, to improve emissions or driveability.

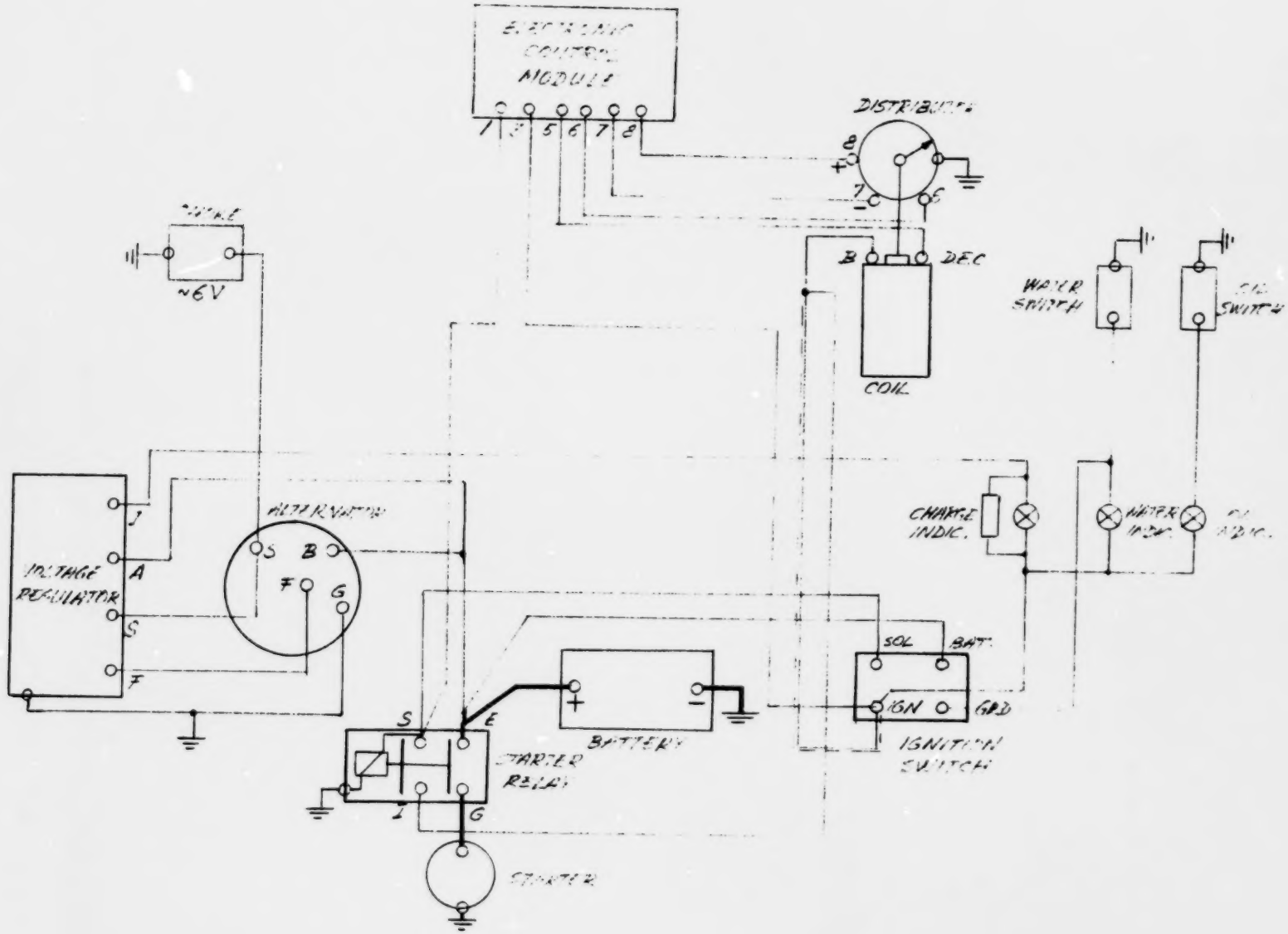


Figure 2-2: Engine electric system for dynamometer application

2.2 TEST EQUIPMENT

The manufacturer of the equipment, principle of operation and the characteristics determining the precision of measurement are listed below:

2.2.1 Dynamometer: 'Go-power' model 557 B, momentum exchange water brake.

Load control: water valve, controlling the filling of the dynamometer body.

2.2.1.1 Dynamometer stator reaction force measuring system: electric strain-gauge load cell, actuated through a rod with self-aligning bearings.

Load cell: 'Interface' - 'Sealed Super-Mini', model SSM-1000 (1000 lb. range)

Non-linearity: $\pm$ 0.05% rated output

Hysteresis: $\pm$ 0.03% rated output

Non-repeatability: $\pm$ 0.02% rated output

Compensated temperature range: 0-150^{o}F

Temperature effect on zero or rated output: $\pm$ 0.08% rated output/100^{o}F

2.2.1.2 Calibration arm

Length: 2 ft.

Torque loading: 4.7 lb. ft.

2.2.1.3 Total calibration weight: 137.489 lb.

Total calibration reading: 279.68 lb.ft.

Average electric calibration reading: 111.26 lb.ft.

Sensitivity: 0.04% FS

Full range setting: 400 lb. ft.

2.2.1.4 Dynamometer speed transducer: 60 teeth gear and magnetic pick-up, 1Hz/1 rpm.

2.2.2 Load cell indicator: 'Lebow' model 7540-154

Excitation: regulated 5V, 3.28 KHz

Non-linearity: $\pm$ 0.005% FS

Temperature effect: 0.15% FS/100^{o}F

Digital display - resolution: 1 part in 10,000

- accuracy: $\pm$ 1 count
- linearity: $\pm$ 0.005% FS
- stability: 0.15% FS/100^{o}F

2.2.3 Speed indicator: 'LEBOW' model 7215-154; digital display characteristics as for 2.2.2

2.2.4 Servo controlled throttle actuator system:

'Labeco' model 304. Angular position control and indication, adjustable for zero and WOT position of the carburettor shaft (indication 0 to 1000)

2.2.5 Balance for fuel consumption measurement:

'Mettler' model PK 36

Range: 0-30,000 g

Readability: 1 g (0.1 g up to 6,000 g, in the 'Delta Range')

Reproducibility: < 0.5 g (< 0.1 g in 'Delta Range')

Linearity: ± 1 g (± 0.1 g in Delta Range)

Temperature range: 0-40°C

2.2.6 Temperature measurement: 'Doric Trendicator' series 400 A with 10 channels switching box and Hy - Cal Eng.' Thermocouples

Thermocouple range: K (Chromel-Alumel)

Range: -350 to 2300°F

Accuracy of indicator: ± 1°F

Junction: grounded

Sheath: Inconel, .125 dia.

2.2.7 Pressure measurement: 'Doric Trendicator' series 400A with 5 channels switching capability and 'Viatran' pressure transducers.

Measuring method: diaphragm with strain-gage bridge

Output: 5V DC FS (amplifier included)

Static-error band: ± 0.4% FS

Temperature effects: ± 2% FS/100°F (compensated limits: -30 to +180°F)

Internal calibration signal accuracy: ÷ 1% FS

Frequency response: flat to 7 Hz (#223, 0-20 in H_2O range; 2 kHz (#218, ± 5 PSI range)

2.2.8 UV Recorder: 'Honeywell CRT Visicorder' model 1858

Frequency range: 0 to 5 kHz (+0, -8%)

Accuracy: ± 0.5% FS adjustable (#1883A Differential Amplifier)

2.2.9 HC/CO/CO_2 emissions analyzer: 'Horiba' model Mexa - 400

Measuring method: non-dispersive infrared

Ranges: 0-250 and 0-1000 ppm HC (n-hexane equivalent)

0-2 and 0-10% CO

0-16% CO_2

Repeatability: ± 5% FS

Response time: 90% of reading in 7 seconds

2.2.10 NO/NO_x emission analyzer: 'Beckman' model 951

Measuring method: chemiluminiscence

Ranges: 0-10, 0-25, 0-100, 0-250, 0-1000, 0-2500 and 0-10,000 ppm.

Sensitivity: 0.1 ppm on 10 ppm range

Linearity: ± 1% FS

Precision: 0.5% FS

Dynamic response: ≤ 1s (≤ 3s on 10 ppm range)

2.2.11 0_2 emission analyzer: 'Teledyne Analytical Instruments' model 320 P-4

Measuring method: Micro-fuel cell

Ranges: 0-5, 0-10, 0-25% 0_2

Sensitivity: ± 0-5% FS

Accuracy: ± 1% FS

Response time: 90% in less than 5s

2.2.12 Exhaust sample conditioning system: BECKMAN, with diaphragm compressor and air dryer

2.2.13 Knock sensor: 'Bruel & Kjaer' piezoelectric accelerometer model 4368 with charge amplifier, 3kHz high-pass filter and headphones
Accelerometer frequency range: 0.2-9.00 kHz (10%)
Maximum accelerometer ambient temperature: 250°C

2.2.14 Engine analyzer - 'Sun' model EET-1120

2.2.15 Engine and dynamometer monitoring gages:
Engine water temperature
Engine oil pressure
Battery charge
Dynamometer water temperature - standard automotive gages.

2.2.16 Barometric pressure: mercury barometer 'Eberbach', 0.01 in. divisions

2.2.17 Ambient temperature: mercury thermometer 'Weksler', 1°F divisions

2.2.18 Water vapour pressure in atmosphere: sling-psychrometer

2.2.19 Exhaust manifolds and pipes cooling fan: 5 HP, electrically driven axial fan

3. CARBURETION SYSTEMS

The IMPCO and BEAM carburetion systems tested in this program have their own carburettor body (IMPCO uses the throttle plate adapter from the original gasoline carburettor). The A.F.S. system is mounted on the top of the gasoline carburettor (with the choke plate blocked open). These three carburettors are representative of three different principles of operation.

Data on each carburetion system, including the principle of operation are presented in Table 3-1.

In Figure 3-1, an exploded view of the IMPCO model E vaporizer/regulator with EC1 emission control device is reproduced.

A cross-section of the BEAM vaporizer/regulator model 450B is shown in Figure 3-2.

In Figure 3-3, a schematic view of the TARTARINI model RS77 3 stage vaporizer/regulator is presented.

Table 3-1: Technical data on propane carburetion systems

Carburetion System	Vaporizer/Regulator		Mixer		Comments
	Stages	Model	Principle	Model	
IMPCO	2	EBS	Air valve	CA 225	
BEAM	2	450B	Venturi	C5-60-H6	Venturi: 341-43 Metering plate: 6C-250-187
A.F.S.	3	TARTARINI (Italy) RP/77 SUPER	Flow nozzle	UM-2	

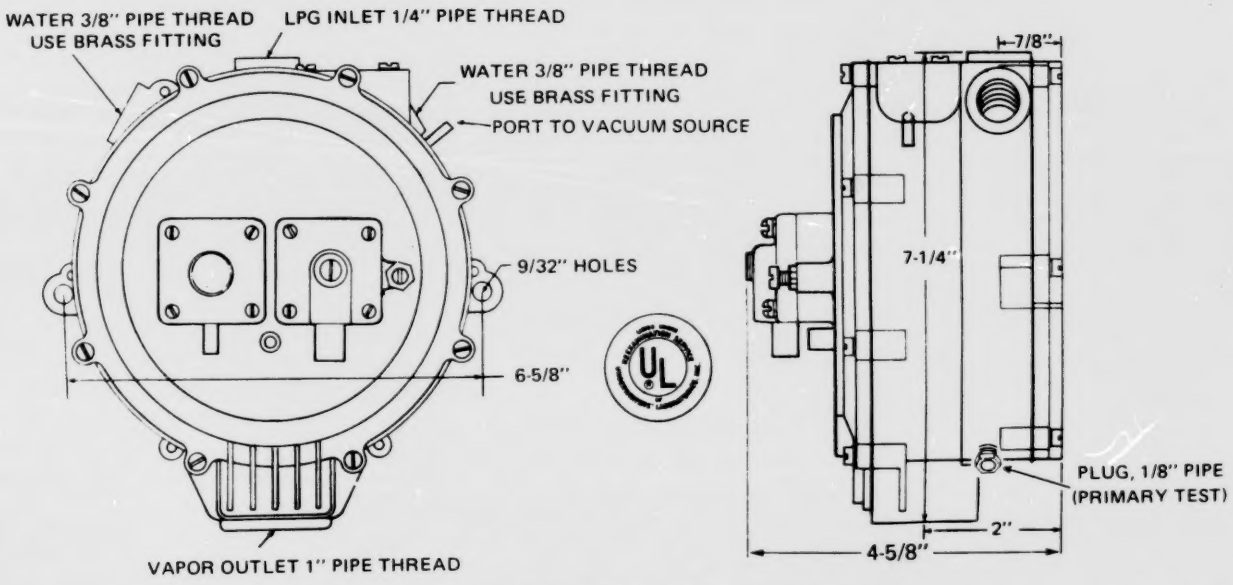
PRODUCT DATA SHEET

IMPCO CARBURETION, INC.
A SUBSIDIARY OF ATTWOOD CORP.

INSTANT POWER!

MODEL E SERIES 20

LP-gas converter with EC1
2 stage – 325 h.p.



Heat exchange body available in aluminum or brass

MODEL	DESCRIPTION
EO-20	Orange spring, with EC1 silicone diaphragm
EOS-20	Orange spring, with EC1 silicone diaphragm and starting valve

EXPLODED VIEW SEE INSIDE

Converters are available with silicone diaphragms.
To order, place a -2 following the converter part number.

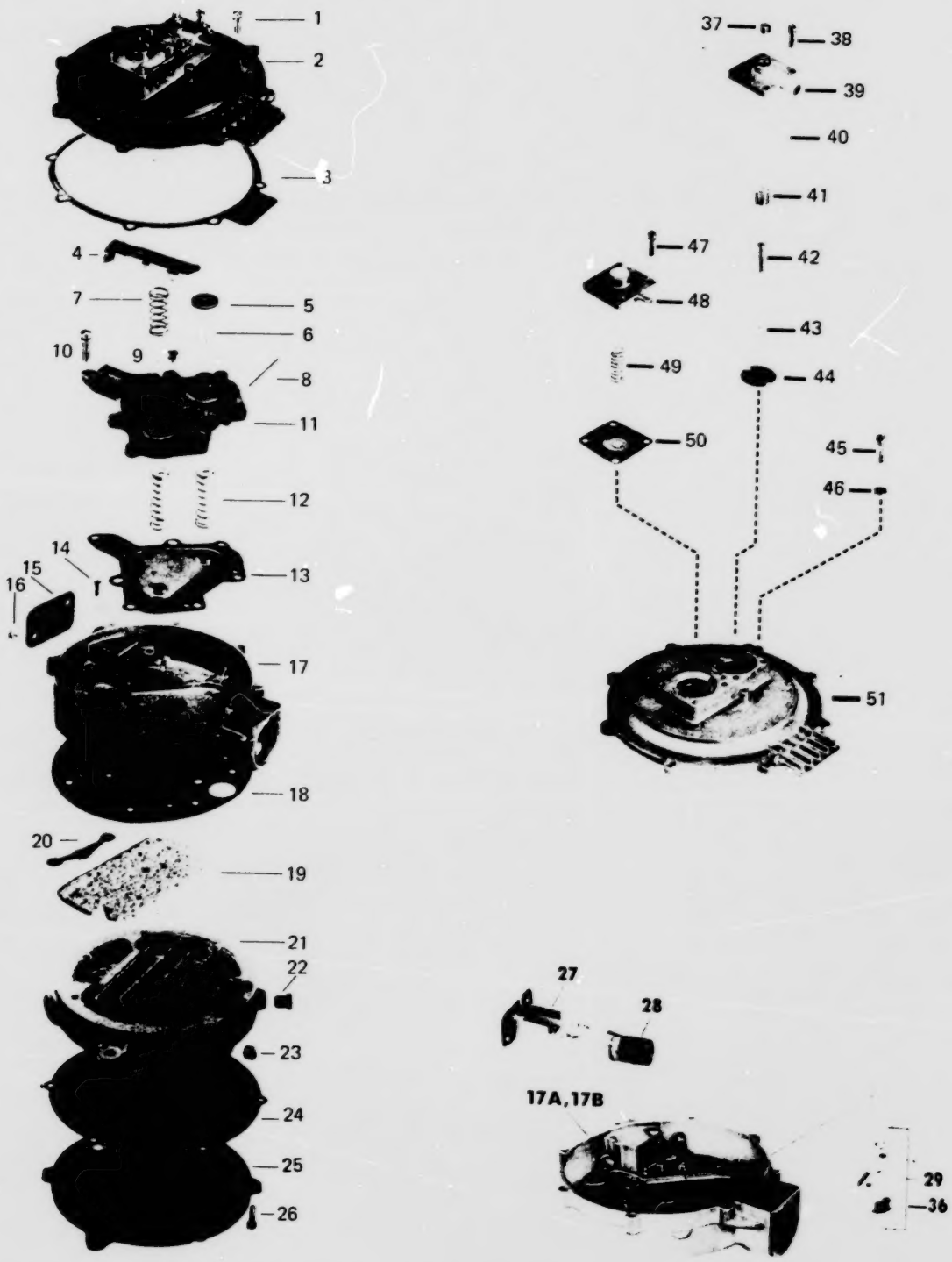


Figure 3-1.1: Exploded view of IMPCO model E vaporizer/regulator with EC1 emission control device

INDEX	PART NO.	DESCRIPTION
1	S1-3	Screw, 10-24 x 5/8" SEMS (8)
2	AC1-49	Cover assy., Model E with EC1,
3	AD1-23	Diaphragm assy., silicone secondary: D1-23, P2-16 (2), L2-1, R2-3(2)
4	AL1-13	Lever assy., secondary: L1-13, P1-8, S3-23
5	S4-6	Seat, secondary
6	P1-9	Pin, secondary seat
7	S2-22	Spring, secondary – blue
7	S2-23	Spring, secondary – orange
8	P1-7	Pin, secondary lever fulcrum
9	S1-40	Screw, 10-24 x 3/8" SEMS (2)
10	S1-39	Screw, 12-24 x 7/8" SEMS (7)
11	C1-20	Cover, primary
12	S2-13	Spring, primary (2)
13	AD1-15	Diaphragm assy., primary: D1-15, L1-14, P2-18, R2-3 (3)
14	P1-11	Pin, primary valve
15	P2-19	Plate, cover (Model EO and EB)
16	S1-12,	Screw, 8-32 x 5/16" SEMS (2)
17	B1-20	Body, regulator (Specify primer)
17A	BB1-20-2	Body, regulator, E series w/starting valve and coil (complete)
17B	CB1-20-2	Body, regulator, E series w/starting valve less coil
18	G1-37	Gasket, regulator body
19	F3-1	Sponge
20	S4-7	Seat, primary
21	AB1-19-1	Body assy., heat exchanger (aluminum)
21	AB1-19-2	Body assy., heat exchanger (brass)
22	P3-13	Plug, 1/8" pipe (Primary test)
23	P3-3	Plug, 1/8" pipe brass (Water drain)
24	G1-35	Gasket, back cover
25	C1-21	Cover, back
26	S1-3	Screw, 10-24 x 5/8" SEMS (6)
STARTING VALVE PARTS		
27	AC2-8	Core assy.: C2-8, C2-9, P2-20, W1-30, S1-66, N1-9(2)
28	C3-1	Coil Primer
29	S2-82	Spring, Valve opening
30	R1-39	Ring, valve seat retainer
31	S4-18	Seat, starting valve
32	P1-15	Pin, retaining
33	L1-54	Lever, Model E starting valve
34	S2-83	Spring, valve closing
35	S1-66	Screw, 8-32 x 1/2"
36	B4-22	Bracket, spring starting valve
EC1 PARTS		
37	P3-16	Plug, 1/16" pipe
38	S1-59	Screw, 8-32 x 5/8" SEMS (4)
39	C1-50	Cover, filter
40	F1-12	Filter
41	S2-68	Spring, valve
42	S1-86	Screw, 6-32 x 7/8" Adjustment
43	S2-67	Spring, adjustment lock
44	V1-22	Valve, disc.
45	S1-84	Screw, 10-32 x 5/8"
46	N1-13	Nut, 10-32
47	S1-59	Screw, 8-32 x 5/8" SEMS (4)
48	C1-51	Cover, diaphragm
49	S2-62	Spring, diaphragm
50	DD1-2	Diaphragm assy. for EC1, D1-2, P1-27, P2-2
51	BC1-49	Cover assy., C1-49, R2-8 (2), L1-52

Figure 3-1.2: IMPCO model E vaporizer/regulator with EC1 - parts list

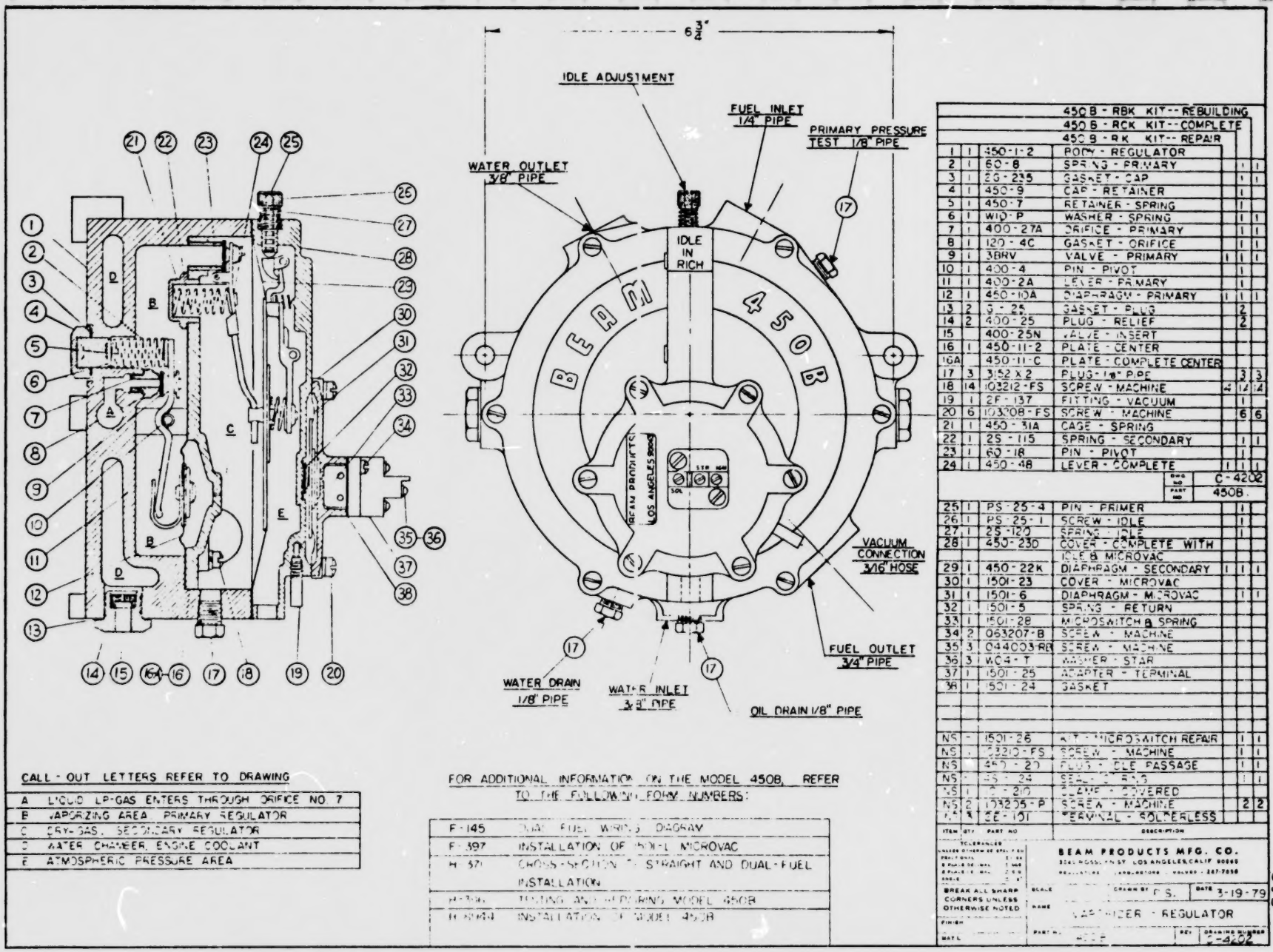
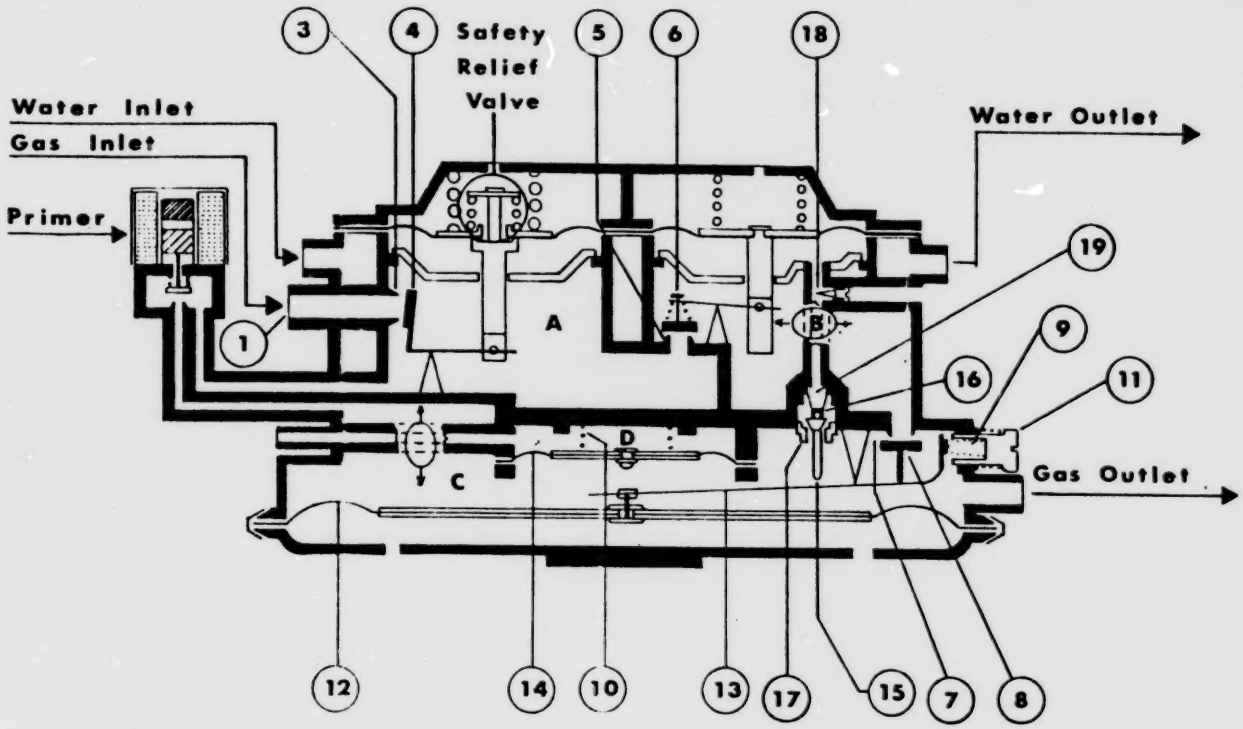

6 3/4"
IDLE ADJUSTMENT
FUEL INLET 1/4" PIPE
PRIMARY PRESSURE TEST 1/8" PIPE
WATER OUTLET 3/8" PIPE
IDLE IN RICH
BEAM 450B
VACUUM CONNECTION 3/16" HOSE
FUEL OUTLET 3/4" PIPE
WATER DRAIN 1/8" PIPE
WATER INLET 3/8" PIPE
OIL DRAIN 1/8" PIPE
CALL - OUT LETTERS REFER TO DRAWING
A LIQUID LP-GAS ENTERS THROUGH ORIFICE NO 7
B VAPORIZING AREA PRIMARY REGULATOR
C DRY-GAS, SECONDARY REGULATOR
D WATER CHAMBER, ENGINE COOLANT
E ATMOSPHERIC PRESSURE AREA
FOR ADDITIONAL INFORMATION ON THE MODEL 450B, REFER TO THE FOLLOWING FORM NUMBERS:
F-145 DUAL FUEL WIRING DIAGRAM
F-397 INSTALLATION OF MODEL MICROVAC
H-371 CROSS-SECTION OF STRAIGHT AND DUAL-FUEL INSTALLATION
H-390 TUNING AND ADJUSTING MODEL 450B
H-404 INSTALLATION OF MODEL 450B
450 B - RBK KIT -- REBUILDING
450 B - RCK KIT -- COMPLETE
450 B - RK KIT -- REPAIR
1 1 450-1-2 BODY - REGULATOR
2 1 60-8 SPRING - PRIMARY
3 1 25-235 GASKET - CAP
4 1 450-9 CAP - RETAINER
5 1 450-7 RETAINER - SPRING
6 1 WID-P WASHER - SPRING
7 1 400-27A ORIFICE - PRIMARY
8 1 120-4C GASKET - ORIFICE
9 1 3BRV VALVE - PRIMARY
10 1 400-4 PIN - PIVOT
11 1 400-2A LEVER - PRIMARY
12 1 450-10A DIAPHRAGM - PRIMARY
13 2 3-25 GASKET - PLUG
14 2 400-25 PLUG - RELIEF
15 400-25N VALVE - INSERT
16 1 450-11-2 PLATE - CENTER
16A 450-11-C PLATE - COMPLETE CENTER
17 3 3152 X 2 PLUG - 1/8" PIPE
18 14 103212-FS SCREW - MACHINE
19 1 2F-137 FITTING - VACUUM
20 6 103208-FS SCREW - MACHINE
21 1 450-31A CAGE - SPRING
22 1 2S-115 SPRING - SECONDARY
23 1 60-18 PIN - PIVOT
24 1 450-48 LEVER - COMPLETE
DWG NO C-4202
PART NO 450B.
25 1 PS-25-4 PIN - PRIMER
26 1 PS-25-1 SCREW - IDLE
27 1 2S-120 SPRING - IDLE
28 1 450-23D COVER - COMPLETE WITH IDLE & MICROVAC
29 1 450-22K DIAPHRAGM - SECONDARY
30 1 1501-23 COVER - MICROVAC
31 1 1501-6 DIAPHRAGM - MICROVAC
32 1 1501-5 SPRING - RETURN
33 1 1501-28 MICROSWITCH & SPRING
34 2 063207-B SCREW - MACHINE
35 3 044003-RR SCREW - MACHINE
36 3 WC4-T WASHER - STAR
37 1 1501-25 ADAPTER - TERMINAL
38 1 1501-24 GASKET
NS - 1501-26 KIT - MICROSWITCH REPAIR
NS - 103210-FS SCREW - MACHINE
NS - 450-20 PLUG - IDLE PASSAGE
NS - PS-24 SEAL - IDLE
NS 1 2-210 FLAME - SHIELD
NS 2 103205-P SCREW - MACHINE
NS 3 SE-101 TERMINAL - SOLDERLESS
ITEM QTY PART NO DESCRIPTION
TOLERANCES UNLESS OTHERWISE SPECIFIED
BREAK ALL SHARP CORNERS UNLESS OTHERWISE NOTED
FINISH
MATL
BEAM PRODUCTS MFG. CO.
3241 ROSSLYN ST LOS ANGELES, CALIF 90065
REGULATORS VAPORIZERS VALVES 227-7050
SCALE
DRAWN BY P.S. DATE 3-19-79
NAME VAPORIZER - REGULATOR
PART NO 450B REV
DRAWING NUMBER C-4202

Figure 3-2: Cross-section of BEAM model 450B vaporizer/regulator

A = high-pressure stage (∿22 psi)
B = medium-pressure stage
C = low-pressure stage
D = engine vacuum



1 = inlet
3 = orifice I stage
4 = valve I stage
5 = orifice II stage
6 = valve II stage
7 = orifice III stage
8 = valve III stage
9 = idle spring
10 = vacuum switch spring
11 = idle screw
12 = III stage diaphragm
13 = III stage lever
14 = vacuum switch diaphragm
15 = injector plunger
16 = injector valve
17 = injector jet
18 = injector adjusting needle
19 = injector spring

Figure 3-3: Schematic view of TARTARINI model RP 77 vaporizer/regulator

4. TEST PROCEDURE

The test procedure is based on the SAE Standard J 816 b - "Engine Test Code - Spark Ignition and Diesel" and "GM Engine Test Code" - VI edition, test 1 - "Full throttle, as installed".

During the test, the *net power* as defined by the SAE Standard is measured, i.e. the engine is equipped with all the built-in accessories (fuel, oil and coolant pumps) and all the accessories necessary to perform its intended functions unaided (intake, exhaust, cooling, electric and emissions control systems). Specifically, this includes:

- air cleaner
- fan
- all standard emissions controls
- catalytic converter
- muffler
- alternator
- starter
- battery

The parameters measured during the test are:

- engine rotational speed, N [rpm]
- torque, T [lb.ft.]
- mass fuel consumption, W [lb]
- inlet air temperature at filter [^{o}F]
- inlet manifold air-fuel charge temperature [^{o}F]
- average exhaust gas temperature [^{o}F]

- exhaust gas temperature in the port of each cylinder [^{o}F]
- spark advance BTDC [^{o}]
- manifold vacuum [in Hg]
- outlet cooling water temperature [^{o}F]
- lubrication oil temperature [^{o}F]
- lubrication oil pressure at filter [psi]
- relative throttle position
- barometric pressure, B [in Hg]
- ambient temperature, t [^{o}F]
- wet and dry bulb temperatures [^{o}F] for water vapour pressure in atmosphere, e [in Hg]
- HC (n-hexane equivalent) emission [ppm]
- CO emission [%]
- CO_2 emission [%]
- NO emission [ppm]

The following parameters are calculated for correction of data at standard ambient conditions:

- brake power, observed (at test conditions), b_{pt} [hp]
- brake mean effective pressure, observed, $bmep_t$ [lb/in^2]
- mechanical efficiency, n [%]
- friction power, observed, fp [hp]
- mass fuel consumption per hour, observed, F_t [lb/h]
- brake specific fuel consumption, observed, $bsfc_t$ [lb/hp·h]
- barametric pressure, corrected for dry air conditions, B_d [in Hg]

- correction factor for standard atmospheric conditions, C_s
- brake power, corrected, bp_c [hp]
- torque, corrected T_c [lb.ft]
- brake mean effective pressure, corrected, $bmep_c$ [lb/in^2]

The calculations are detailed in Appendix 1.

The air-fuel ratio (A/F) is calculated from the emission components (HC, CO, CO_2, O_2 and NO). The theoretical background of the method is presented in Appendix 2. The various sytems operations during the test are listed below:

a) stabilize thermal regime of the engine.
b) measure and record atmospheric conditions.
c) load the engine at WOT (wide open throttle) to obtain the minimum stabilized speed and record the listed parameters for a 3 minute period.
d) decrease the load at the same speed at 2/3, 1/3 and minimum obtainable from maximum load and record the listed parameters for a 3 minute period.
e) repeat steps c and d each 500 rpm, up to 3500 rpm, to cover the peak obtainable power for the test engine.
f) repeat all the steps a to e to check for consistency of data.

The baseline test with gasoline was conducted with the following settings:

- static timing 6° BTDC at max. 800 rpm (instruction on the emissions sticker of the engine)
- 190± 10°F thermostatic control of cooling water outlet from engine (SAE for dynamometer testing)
- all emissions controls in place and operational

The evaluation tests with propane were conducted at the settings listed below, recommended by the majority of propane carburetion systems supplies:

- 190°F thermostatic control of cooling water outlet from engine
- spark plugs with gap reduced to 0.035 in (-0.010 in.)
- static timing: 14°BTDC @ 600 rpm
- distributor with centrifugal advance springs replaced (to obtain the quickest rise to 30° total timing and the return of weights at idle)
- vacuum advance isolated
- EGR valve in place, isolated
- early fuel evaporation system isolated

The fuel used for the baseline testing was regular grade unleaded gaosline. An automotive commercial grade of propane was used for the main tests.

5. TEST RESULTS AND INTERPRETATION

5.1 PRELIMINARY

The test results are presented in their final form. That is, all data have been corrected to standard conditions, averaged and reduced. The raw data are available upon request. All data values represent the average of at least two test runs (four for gasoline and IMPCO).

5.2 CORRECTED BRAKE POWER

Table 5-1 and Figure 5-1 give corrected brake power at wide open throttle (WOT). For ease of comparison, for each data point, the percentage difference between each propane carburetion system and the gasoline system is also presented. The power developed with propane is approximately equal to that developed with gasoline for the BEAM carburetion system. However, a power reduction of up to 5.88% was observed for other systems. The main reason for the difference in power output is the leaner air-fuel ratio (A/F) at which the engine is running for the IMPCO and AFS systems, as can be observed in Figure 5-2. The inlet charge temperature is presented in Table 5-2 and Figure 5-3. A reduction in the preheating of the propane in the inlet manifold, especially at WOT, could be beneficial in increasing the power output. The higher than average temperature of the charge for the BEAM system can be explained as a consequence of an overdesigned heat exchanger water-propane.

5.3 MEASURED BRAKE SPECIFIC FUEL CONSUMPTION

Tables 5-3 to 5-5 contain the measured brake specific fuel consumption (BSFC) for 100% load (WOT) and for 66 and 33% of maximum load. Table 5-6 gives the total fuel consumption per hour for approximately zero load. Figure 5-4 presents the same results in graphical form. On this mass base, the propane systems have a consistently lower specific fuel consumption (2.83...24.80%).

The energy base comparison is presented in Tables 5-7 to 5-10, and in Fig. 5-5, allowing a direct analysis of efficiencies of the propane systems versus gasoline. The spread of values is smaller than in the previous report on the GM 229 CID engine. The main reason for this is that the propane carburetion systems tested now are all of an acceptable level of design. The average changes in energy efficiency are presented in Table 5-11. The improvement ranges between 13.87...15.56% for zero and 100% load, 7.43% for 2/3 load and 2.44% for 1/3 load. The causes of decreased efficiency at partial loads are analysed in the chapter on optimization. For this stage of the report it is worth noting that the total timing is constant - approximately equal with 32^{o} for all test speeds. Also, it must be noted that the results are more favourable for propane at partial loads on this model of engine, because of the different calibrations of the gasoline carburetor. On the GM 229 CID, the ROCHESTER DUALJET 210 was calibrated for an equivalence ratio of 0.91...0.97 at WOT and 1.10...1.16

at partial loads. On the FORD 300 CID, the CARTER YFR - 1V is calibrated for 0.85...0.90 at WOT and 0.95...1.03 at partial loads. Running richer at partial loads, the CARTER carburettor made the comparison more favourable for the propane systems. The correlation between the specific fuel consumption and the air-fuel ratio is presented in Figure 5-7 to 5-9. The systems running leaner show an improved fuel economy - 6 to 7% for each point of A/F ratio at WOT and 3 to 4.5% at partial loads (with a slower improvement or even a reverted trend at equivalence ratios higher than 1.10)

For a commercial comparison of prices of the two fuels sold in volumetric units, the results are presented on a volume base in Tables 5-12 to 5-15. Due to the difference in density, compensated in part by the increased efficiency of the propane carburetion, the volumetric consumption of propane is higher, on average, with 16.4% at WOT, 27.7% at 66% load, 35.1% at 33% load and 24.5% at zero load. The overall average is a 24.5% increase in volumetric consumption (the average increase in fleets experimenting with propane is 18...25%).

5.4 MANIFOLD VACUUM

The values of manifold vacuum are indicated in Table 5-16 and Figure 5-10. The load defines clearly the limits of vacuum: 0.5 to 4 in.Hg for WOT, 4.5 to 10.5 for 2/3 load, 13.5 to 18.5 for 1/3 load and 18.5 to 23.5 for zero load. This fact can be useful in the control of the carburetion system A/F ratio as a function of load, using vacuum as a feedback signal.

5.5 TOTAL SPARK ADVANCE

The total spark advance (timing) is presented in Table 5-17 and Figure 5-11. With the vacuum advance isolated in those commercial applications, the total advance represents the sum of initial and centrifugal advance (with weaker springs). The possibilities of optimizing the timing are analyzed in a later chapter.

5.6 RELATIVE THROTTLE POSITION

The relative throttle position is presented in Table 5-18, with differences being determined by the internal resistance to flow of different systems and by the A/F ratio of the particular system.

5.7 EXHAUST GAS TEMPERATURE

5.7.1 Average Downstream Temperature

In Table 5-19 and Figure 5-12 the average exhaust temperatures are recorded. The temperatures are higher for gasoline at WOT (except 3500 rpm). At partial loads the gasoline and propane systems have intermixed temperature fields, with higher values for gasoline at low speeds and for propane at high speeds. The correlation between exhaust temperature and A/F ratio is presented in Figure 5-13 and 5-14.

5.7.2 Cylinder Temperatures

The distribution of exhaust gas temperatures among cylinders is recorded in Tables 5-20 to 5-22 and in Figures 5-15 to 5-17.

5.8 HYDROCARBONS EMISSION

The results for HC emission are presented in Table 5-23 and Figure 5-18. For propane systems, the HC concentration is generally smaller than for gasoline, determined by the A/F ratio at which every system is running. The propane systems tested in this report, of a more consistent quality than some systems tested on GM 229 CID engine, show lower levels of HC emission and the spread of results is reduced.

5.9 CARBON MONOXIDE EMISSION

The results for CO emission are given in Table 5-24 and Figure 5-19. The level of this emission are consistently lower for the propane carburetion systems and as with the previous variable, the results show less spread.

5.10 CARBON DIOXIDE EMISSION

CO_2 emission results are presented in Table 5-25. This variable shows a maximum in the stoichiometric region.

5.11 EXCESS OXYGEN

The results for O_2 emission are recorded in Table 5-26 and Figure 5-20. The level of the excess oxygen is generally higher for the propane systems, as a result of the leaner air-fuel mixtures. The uniformity of the curves for the BEAM system, with values between 2.5 and 3.5% at partial loads should be noted.

5.12 NITRIC OXIDE EMISSION

NO emission results are presented in Table 5-27 and Figure 5-21. The levels of this emission for the propane systems are considerably higher.

For correct calculation of air-fuel ratio for the gasoline carburetion system, the values of emissions for this system are presented with the air pump inactive. In Table 5-28, the values of all emissions for the gasoline system with the air pump active are recorded. This represents a vehicle set up to pass the official emission standards.

5.13 AIR-FUEL RATIO

The air-fuel ratio, calculated from the emission values, is presented in Tables 5-29, 5-30 and in Figure 5-22. The effect of the specific design of the gasoline carburetor, with A/F ratio approximately 1.0 at partial loads can be observed. By comparison, the economy of the propane carburetion systems, with A/F ratio increasing to 1.25 is enhanced.

5.14 POST-TEST ENGINE CONDITION

At the end of 124 hours of the test program, the engine was in sound mechanical condition. An oil leakage through the valve guides was present from the beginning of the tests but this seems to be more of a general problem for this model of engine.

Table 5-1: Performance (Maximum power)

$\frac{\text{hp}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]					
	1600	2000	2500	3000	3250	3500
Gasoline-original	73.26	91.26	107.17	120.27	124.26	123.40
IMPCO	70.54 / -3.72	89.16 / -2.30	107.40 / +0.21	120.34 / +0.06	124.46 / +0.16	123.82 / +0.34
IMPCO + ECI	68.95 / -5.88	87.13 / -4.53	105.85 / -1.23	114.75 / -4.59	117.82 / -5.18	118.63 / -3.87
BEAM	72.36 / -1.23	89.56 / -1.86	108.34 / +1.09	122.10 / +1.52	123.46 / -0.64	123.37 / -0.02
A.F.S.	70.55 / -3.70	88.59 / -2.93	107.93 / +0.71	118.23 / -1.70	121.19 / -2.47	120.33 / -2.49

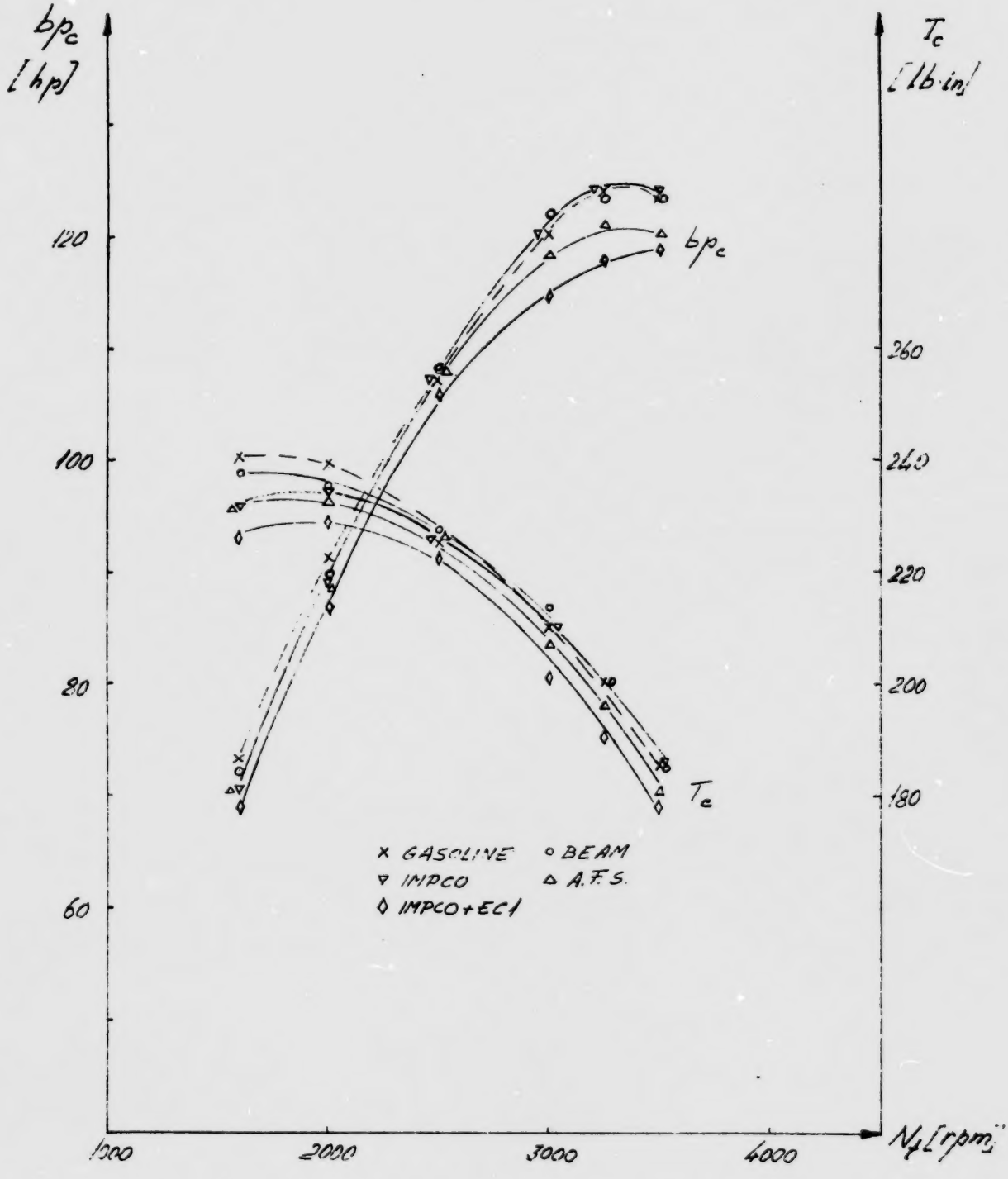


Figure 5-1: Comparison of power at wide open throttle

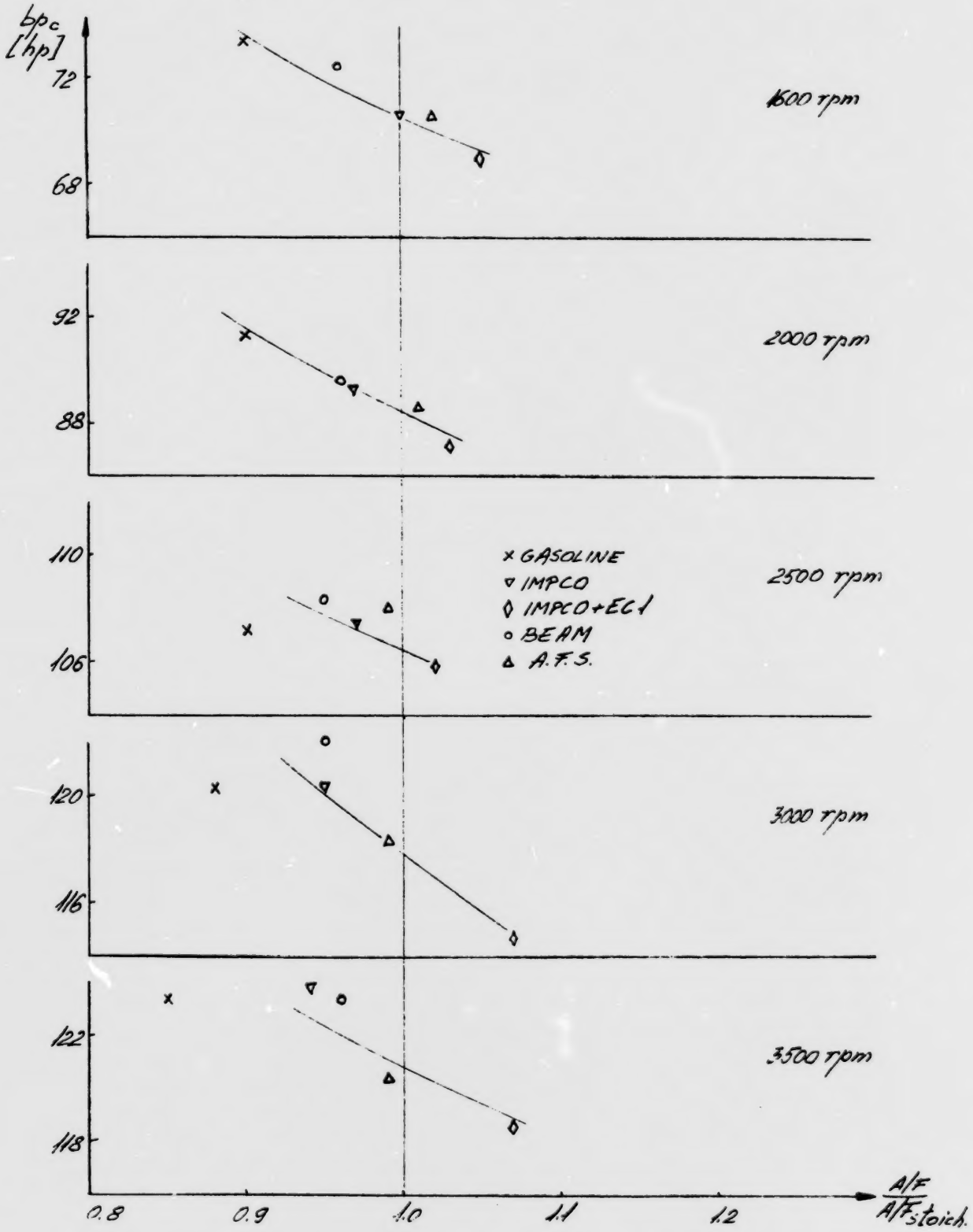


Figure 5-2: Correlation between WOT power and A/F ratio

Table 5-2: Inlet manifold air-fuel charge temperature ^{o}F

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE	-	41	43	48	49	51
	IMPCO	-	106	106	106	107	112
	IMPCO + ECI	-	96	100	106	105	108
	BEAM	-	118	117	115	111	117
	A.F.S.	-	100	100	104	105	109
66	GASOLINE	-	119	120	127	126	127
	IMPCO	-	105	107	105	107	107
	IMPCO + ECI	-	99	101	104	104	105
	BEAM	-	123	119	112	105	109
	A.F.S.	-	104	103	102	101	104
33	GASOLINE	-	145	143	141	135	132
	IMPCO	-	108	106	96	96	98
	IMPCO + ECI	-	98	93	94	93	95
	BEAM	-	127	121	109	102	103
	A.F.S.	-	105	103	98	95	99
20	GASOLINE	151	104	92	107	113	125
	IMPCO	140	119	116	101	103	99
	IMPCO + ECI	132	112	105	96	98	92
	BEAM	137	131	127	117	114	119
	A.F.S.	142	111	110	103	101	107

From 2500 rpm the engine forced ventilation is turned on. For all tests cooling water temperature at outlet was 190 $\pm$ 10 ^{o}F.

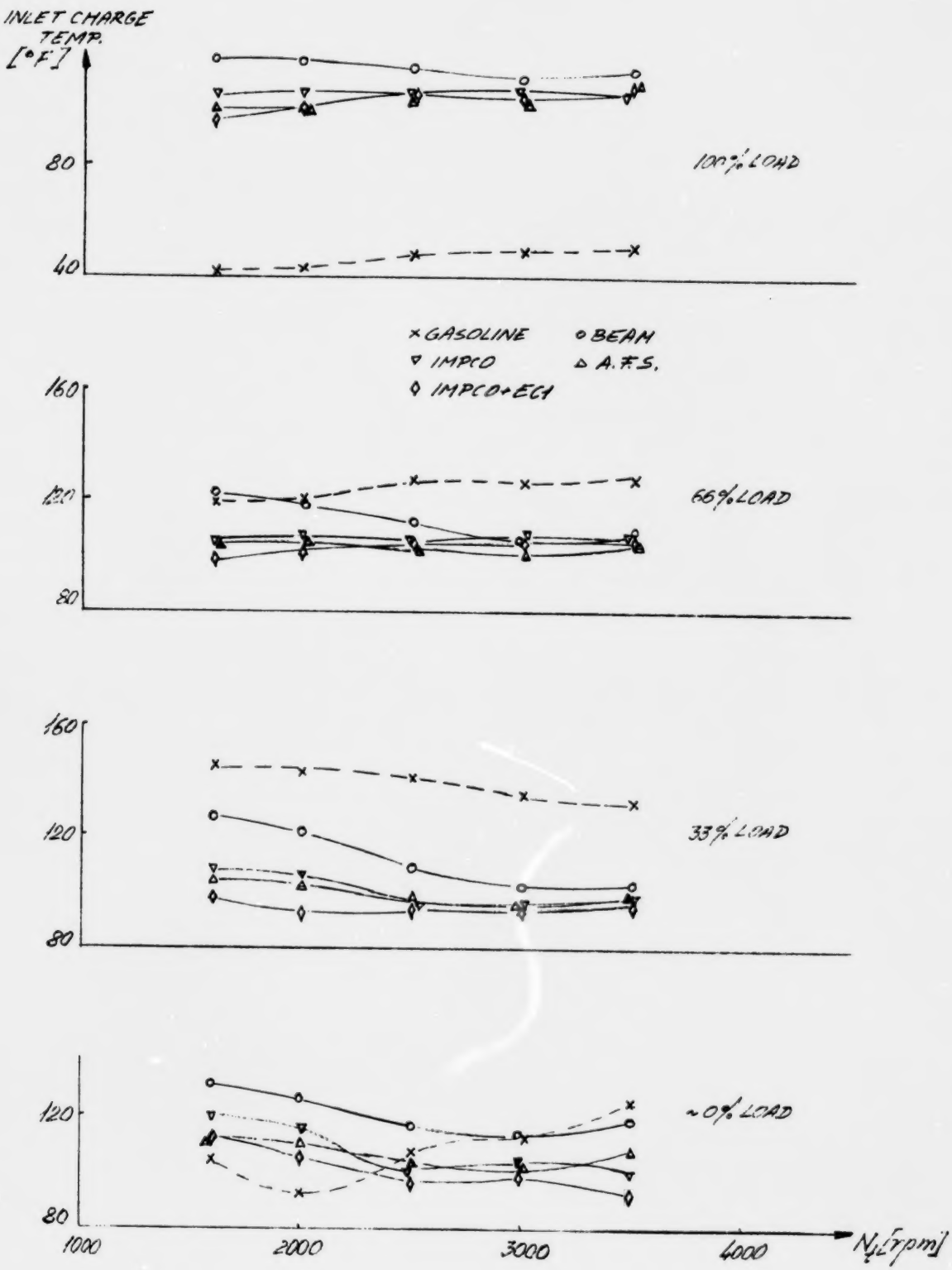


Figure 5-3: Inlet manifold air-fuel charge temperature

Table 5-3: Brake specific fuel consumption

Mass Base - 100% load

$\frac{\text{lb/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]					
	1600	2000	2500	3000	3250	3500
Gasoline-original	.481	.482	.502	.518	.532	.563
IMPCO	$\frac{.387}{-19.54}$	$\frac{.388}{-19.50}$	$\frac{.405}{-19.32}$	$\frac{.429}{-17.18}$	$\frac{.444}{-16.54}$	$\frac{.465}{-17.41}$
IMPCO + ECI	$\frac{.377}{-21.62}$	$\frac{.386}{-19.92}$	$\frac{.389}{-22.51}$	$\frac{.407}{-21.43}$	$\frac{.420}{-21.05}$	$\frac{.433}{-23.09}$
BEAM	$\frac{.389}{-19.13}$	$\frac{.402}{-16.60}$	$\frac{.414}{-17.53}$	$\frac{.429}{-17.18}$	$\frac{.445}{-16.36}$	$\frac{.460}{-18.29}$
A.F.S.	$\frac{.379}{-21.21}$	$\frac{.379}{-21.37}$	$\frac{.390}{-22.31}$	$\frac{.408}{-21.24}$	$\frac{.418}{-21.43}$	$\frac{.442}{-21.49}$

Table 5-4: Brake specific fuel consumption

Mass Base - 66% load

$\frac{\text{lb/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	.459	.462	.482	.507	.538
IMPCO	$\frac{.416}{-9.37}$	$\frac{.417}{-9.74}$	$\frac{.434}{-9.96}$	$\frac{.461}{-9.07}$	$\frac{.491}{-8.74}$
IMPCO + ECI	$\frac{.401}{-12.64}$	$\frac{.408}{-11.69}$	$\frac{.415}{-13.90}$	$\frac{.435}{-14.20}$	$\frac{.477}{-11.34}$
BEAM	$\frac{.389}{-15.25}$	$\frac{.400}{-13.42}$	$\frac{.421}{-12.66}$	$\frac{.427}{-15.78}$	$\frac{.467}{-13.20}$
A.F.S.	$\frac{.392}{-14.60}$	$\frac{.401}{-13.20}$	$\frac{.423}{-12.24}$	$\frac{.440}{-13.22}$	$\frac{.487}{-9.48}$

Table 5-5: Brake specific fuel consumption

Mass Base - 33% load

$\frac{\text{lb/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	.541	.545	.574	.600	.680
IMPCO	$\frac{.500}{-7.58}$	$\frac{.504}{-7.52}$	$\frac{.541}{-5.75}$	$\frac{.583}{-2.83}$	$\frac{.646}{-5.00}$
IMPCO + ECI	$\frac{.499}{-7.76}$	$\frac{.504}{-7.52}$	$\frac{.530}{-7.67}$	$\frac{.552}{-8.00}$	$\frac{.615}{-9.56}$
BEAM	$\frac{.495}{-8.50}$	$\frac{.515}{-5.50}$	$\frac{.542}{-5.57}$	$\frac{.549}{-8.50}$	$\frac{.613}{-9.85}$
A.F.S.	$\frac{.488}{-9.80}$	$\frac{.502}{-7.89}$	$\frac{.533}{-7.14}$	$\frac{.573}{-4.50}$	$\frac{.637}{-6.32}$

Table 5-6: Brake fuel consumption

Mass Base - ∿0% load

lb/h / % vs. gasoline , average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	6.27	7.75	11.20	14.65	18.35
IMPCO	5.69 / -9.25	6.99 / -9.81	8.94 / -20.18	11.50 / -21.50	14.81 / -19.29
IMPCO + ECI	5.42 / -13.56	6.79 / -12.39	9.04 / -19.29	11.82 / -19.32	14.47 / -21.14
BEAM	5.21 / -16.91	6.42 / -17.16	9.62 / -14.11	11.11 / -24.16	14.07 / -23.32
A.F.S.	5.34 / -14.83	6.68 / -13.81	8.62 / -23.04	10.55 / -27.99	13.80 / -24.80

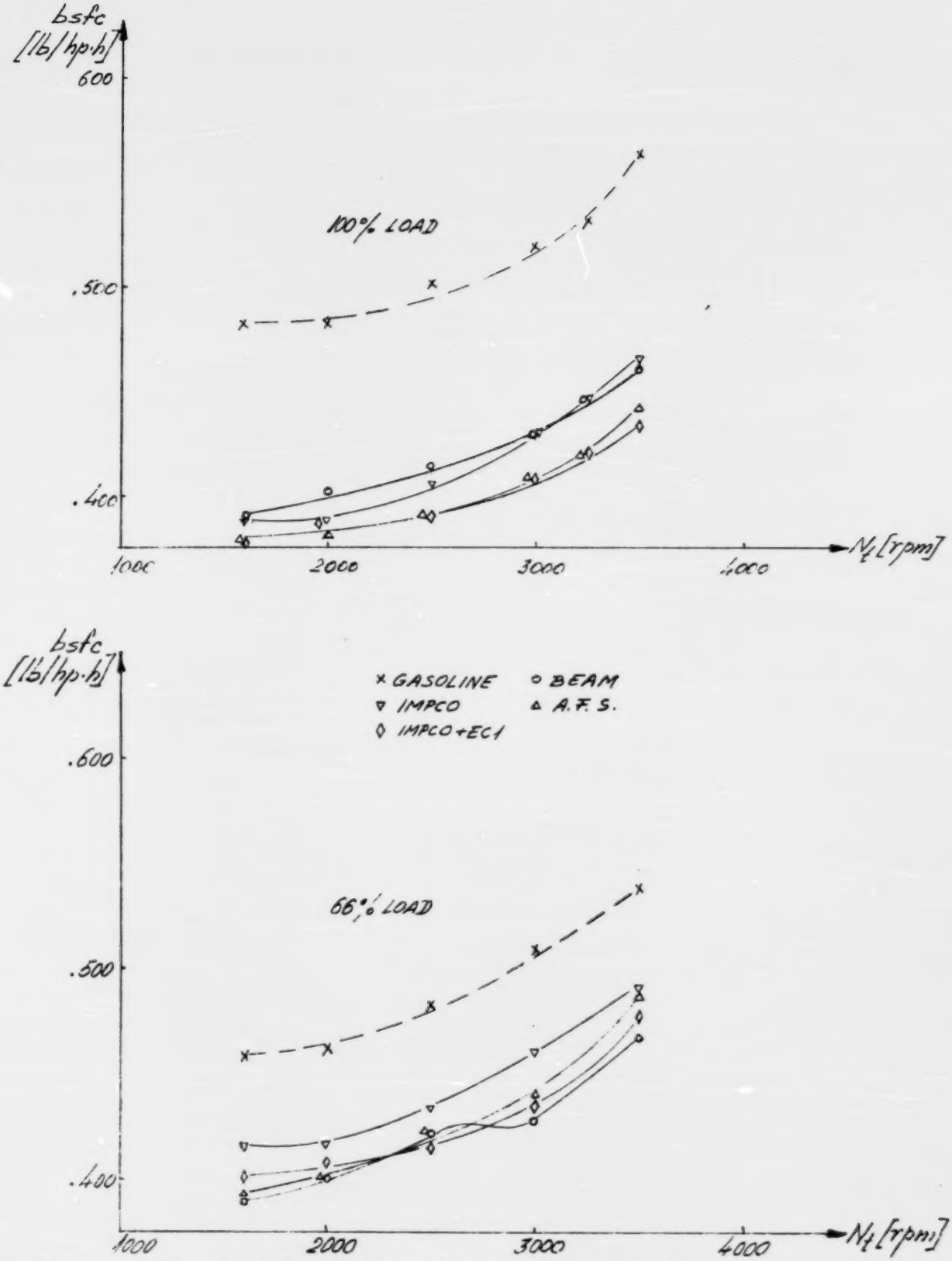


Figure 5-4.1: Comparison of brake specific fuel consumption-mass base

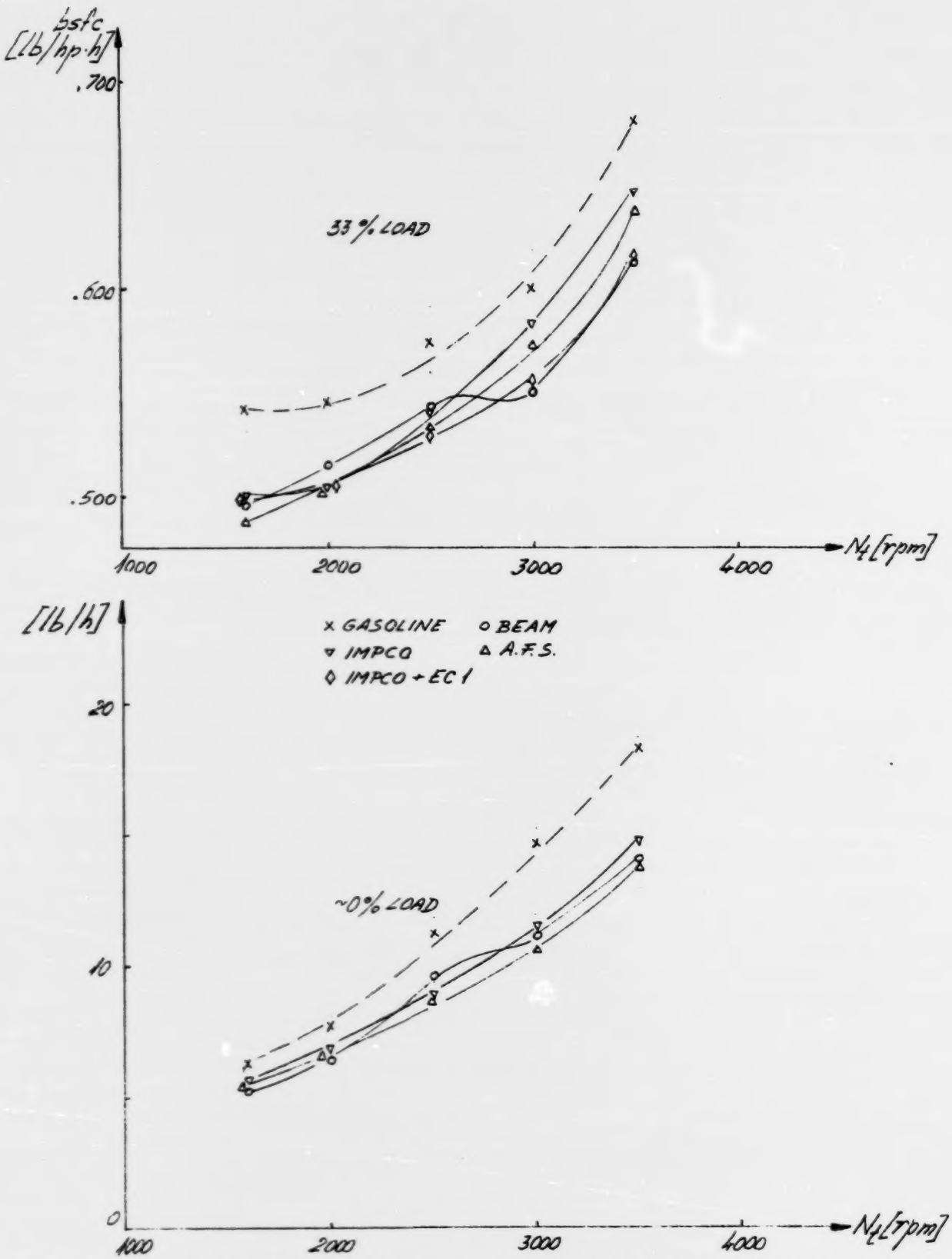


Figure 5-4.2: Comparison of brake specific fuel consumption-mass base (continuation)

Table 5-7: Brake specific fuel consumption

Energy Base - 100% load

$\frac{\text{kcal/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]					
	1600	2000	2500	3000	3250	3500
Gasoline-original	2293	2298	2393	2469	2536	2684
IMPCO	1945 -15.18	1950 -15.14	2035 -14.96	2156 -12.68	2231 -12.03	2337 -12.93
IMPCO + ECI	1894 -17.38	1940 -15.59	1955 -18.31	2045 -17.17	2110 -16.78	2176 -18.93
BEAM	1955 -14.75	2020 -12.10	2080 -13.07	2156 -12.69	2236 -11.82	2311 -13.88
A.F.S.	1904 -16.96	1904 -17.15	1960 -18.09	2050 -16.97	2100 -17.19	2221 -17.25

Net Heat of Combustion @ 25°C, constant p:

- propane: 11,078 kcal/kg (5,025 kcal/lb)
- gasoline: 10,510 kcal/kg (4,767 kcal/lb)

Table 5-8: Brake specific fuel consumption

Energy Base 66% load

$\frac{\text{kcal/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	2188	2202	2298	2417	2565
IMPCO	2090 -4.48	2095 -4.86	2181 -5.09	2317 -4.14	2467 -3.82
IMPCO + ECI	2015 -7.91	2050 -6.89	2085 -9.25	2186 -9.56	2397 -6.55
BEAM	1955 -10.66	2010 -8.72	2116 -7.94	2146 -11.23	2347 -8.51
A.F.S.	1970 -9.96	2015 -8.49	2126 -7.48	2211 -8.52	2447 -4.60

Table 5-9: Brake specific fuel consumption

Energy Base 33% load

$\frac{\text{kcal/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	2579	2598	2736	2860	3242
IMPCO	2513 / -2.56	2533 / -2.50	2719 / -0.62	2930 / +2.45	3246 / +0.12
IMPCO + ECI	2507 / -2.77	2533 / -2.52	2663 / -2.66	2774 / -3.01	3090 / -4.68
BEAM	2487 / -3.55	2588 / -0.39	2724 / -0.46	2759 / -3.54	3080 / -4.99
A.F.S.	2452 / -4.92	2523 / -2.89	2678 / -2.12	2879 / +0.66	3201 / -1.26

Table 5-10: Brake fuel consumption

Energy Base ∿0% load

$\frac{\text{kcal/h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	29889	36944	53390	69837	87474
IMPCO	28592 / -4.34	35125 / -4.92	44924 / -15.86	57788 / -17.25	74420 / -14.92
IMPCO + ECI	27235 / -8.88	34120 / -7.64	45426 / -14.92	59395 / -20.06	72712 / -16.88
BEAM	26180 / -12.41	32260 / -12.68	48340 / -9.46	55828 / -20.06	70702 / -19.17
A.F.S.	26834 / -10.22	33567 / -9.14	43316 / -18.87	53014 / -24.09	69345 / -20.73

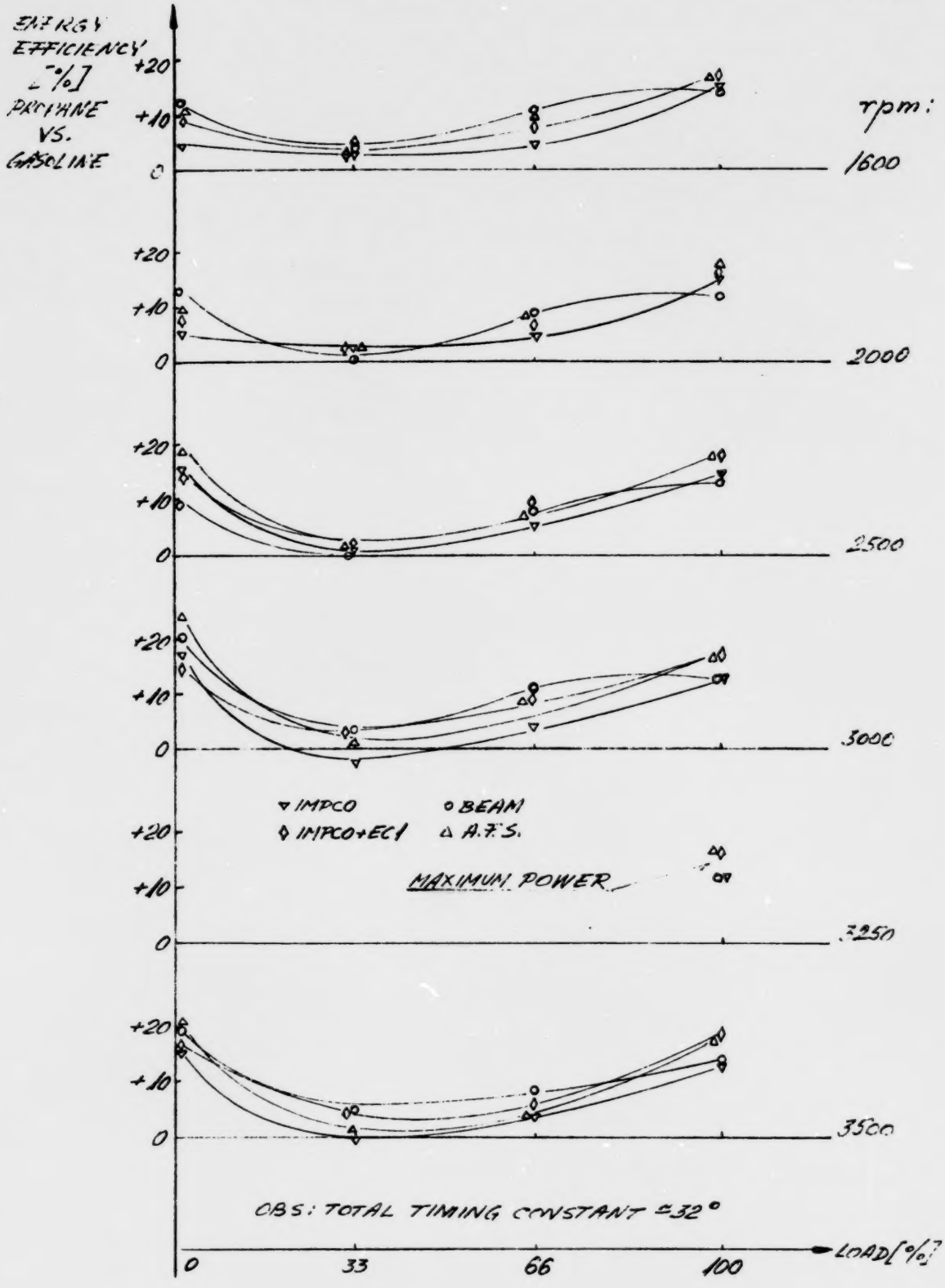


Figure 5-5: Energy efficiency of propane carburetion systems vs. gasoline

Table 5-11: Changes in energy efficiency [%] for the propane carburetion systems vs. gasoline

Load [%]	Carburetion system	Engine speed [rpm] 1600	2000	2500	3000	3500	Average
		Average for 4 sytems					
100*	-	+16.07	+15.00	+16.11	+14.88	+15.75	+15.56
66	-	+8.25	+7.24	+7.44	+8.36	+5.87	+7.43
33**	-	+3.45	+2.08	+1.47	+2.42	+2.76	+2.44
∿0	-	+8.96	+8.60	+14.78	+19.09	+17.93	+13.87
		Maximum for some selected systems*					
66	BEAM IMPCO + ECI	+10.66	+8.72	+9.25	+11.23	+8.51	+9.67
33**	A.F.S. IMPCO + ECI BEAM	+4.92	+2.89	+2.66	+3.54	+4.99	+3.80
∿0	BEAM A.F.S.	+12.41	+12.68	+18.87	+24.09	+20.73	+17.76

* for WOT load, the systems running leaner have increased energy efficiency at decreased power. The systems selected exhibit a compromise of acceptable power and energy efficiency.

** total advance $(30...33)^{o}$. Far from optimum for 33 and 0% loads.

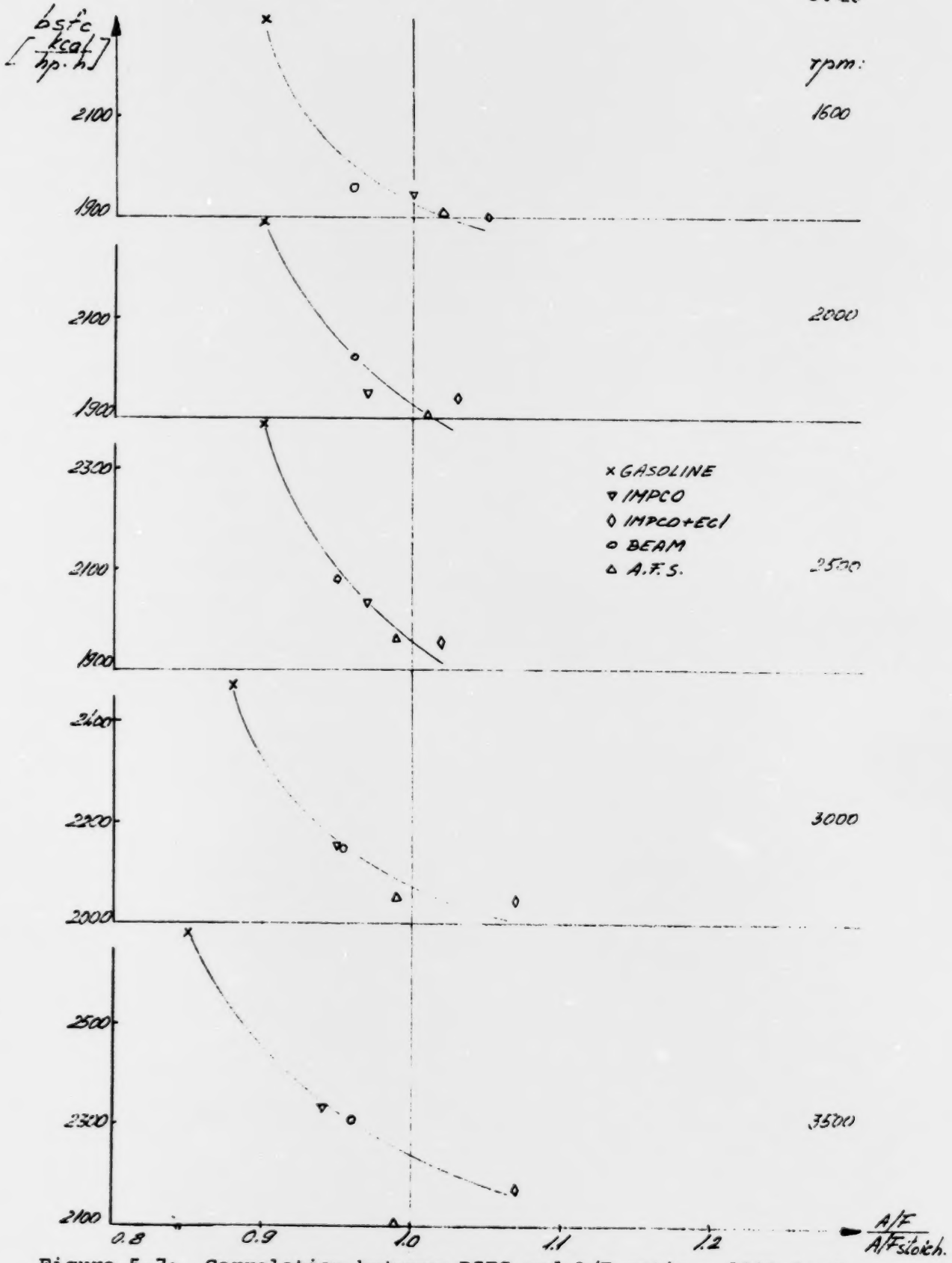


Figure 5-7: Correlation between BSFC and A/F ratio - 100% load

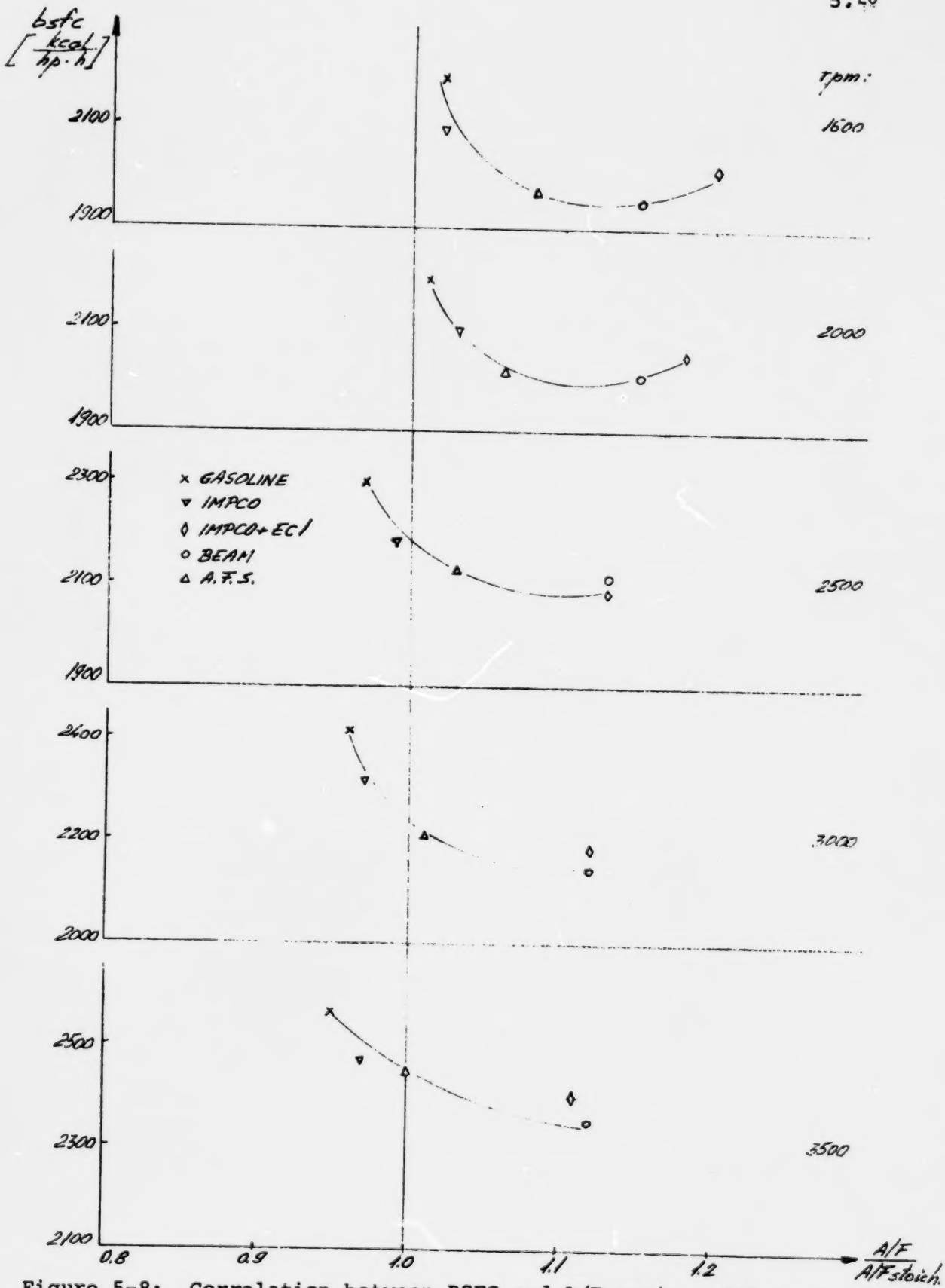


Figure 5-8: Correlation between BSFC and A/F ratio - 66% load

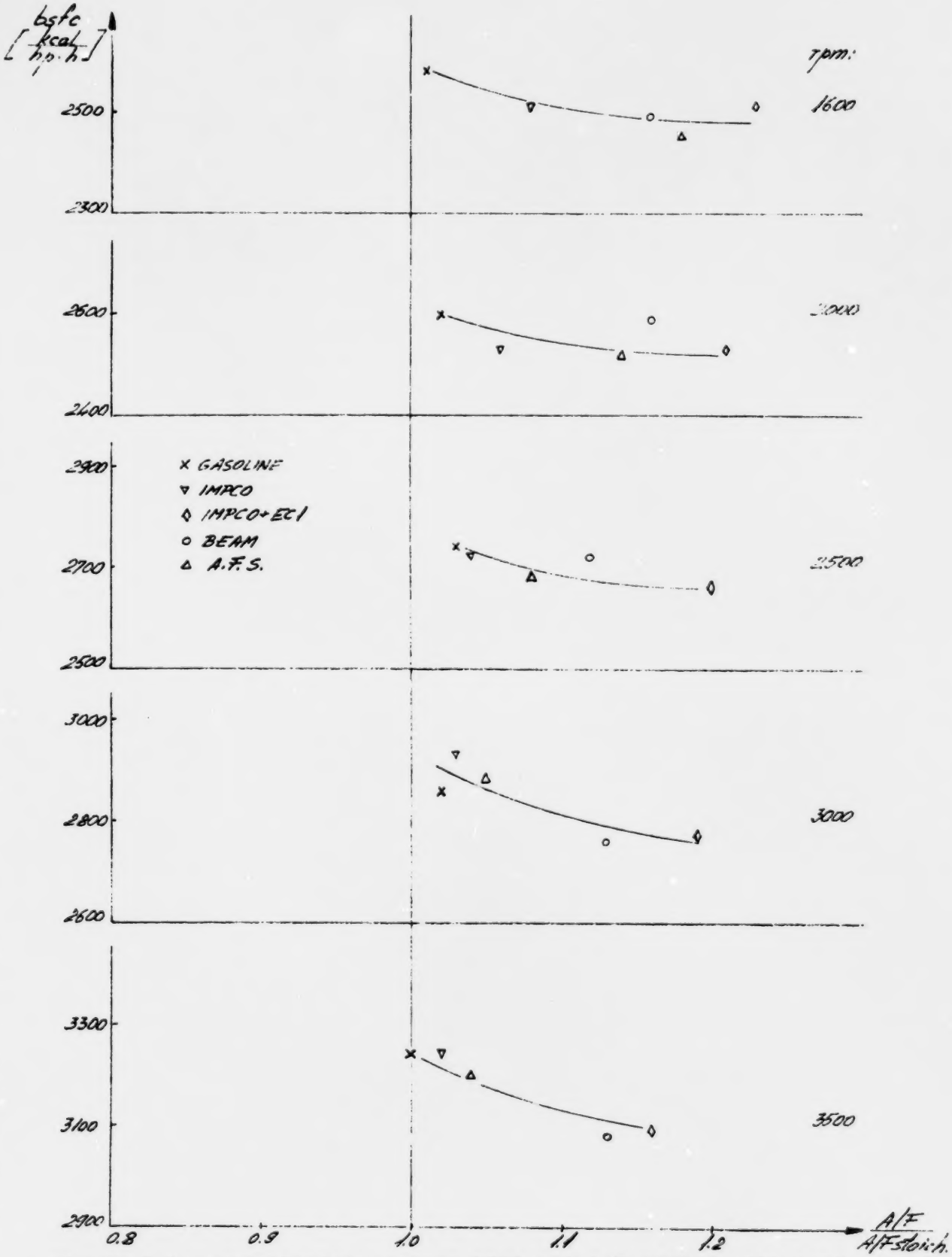


Figure 5-9: Correlation between BSFC and A/F ratio - 33% load

Table 5-12: Brake specific fuel consumption

Volume Base - 100% load

$\frac{\text{l/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]					
	1600	2000	2500	3000	3250	3500
Gasoline-original	.296	.297	.309	.319	.327	.347
IMPCO	.346 +16.89	.347 +16.84	.362 +17.15	.384 +20.38	.397 +21.41	.416 +19.88
IMPCO + ECI	.337 +13.97	.345 +16.29	.348 +12.65	.364 +14.16	.376 +14.93	.387 +11.66
BEAM	.348 +17.59	.360 +21.11	.370 +19.89	.384 +20.33	.398 +21.77	.412 +18.62
A.F.S.	.339 +14.53	.339 +14.14	.349 +12.95	.365 +14.42	.374 +14.37	.396 +14.12

Density of liquid @ 60°F:

- propane 0.5069 kg/l (0.8948 l/lb)
- gasoline 0.7370 kg/l (0.6155 l/lb)

Table 5-13: Brake specific fuel consumption

Volume Base - 66% load

$\frac{\text{l/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	.283	.284	.297	.312	.331
IMPCO	.372 +31.45	.373 +31.34	.388 +30.64	.413 +32.37	.439 +32.63
IMPCO + ECI	.359 +26.79	.365 +28.55	.371 +25.03	.389 +24.76	.427 +28.95
BEAM	.348 +23.00	.358 +26.03	.377 +26.84	.382 +22.46	.418 +26.24
A.F.S.	.351 +24.03	.359 +26.41	.379 +27.61	.394 +26.28	.436 +31.72

Table 5-14: Brake specific fuel consumption

Volume Base - 33% load

$\frac{\text{l/hp·h}}{\text{\% vs. gasoline}}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	.333	.335	.353	.369	.419
IMPCO	$\frac{.447}{+34.23}$	$\frac{.451}{+34.63}$	$\frac{.484}{+37.11}$	$\frac{.522}{+41.46}$	$\frac{.578}{+37.95}$
IMPCO + ECI	$\frac{.447}{+34.09}$	$\frac{.451}{+34.62}$	$\frac{.474}{+34.35}$	$\frac{.494}{+33.86}$	$\frac{.550}{+31.34}$
BEAM	$\frac{.433}{+33.01}$	$\frac{.461}{+37.56}$	$\frac{.485}{+37.39}$	$\frac{.491}{+33.13}$	$\frac{.549}{+30.91}$
A.F.S.	$\frac{.437}{+31.23}$	$\frac{.449}{+34.03}$	$\frac{.477}{+35.13}$	$\frac{.513}{+39.02}$	$\frac{.570}{+36.04}$

Table 5-15: Brake fuel consumption

Volume Base - ∿0% load

$\frac{l/h}{\%\ vs.\ gasoline}$, average values

Carburetion system	Engine speed [rpm]				
	1600	2000	2500	3000	3500
Gasoline-original	3.86	4.77	6.89	9.02	11.29
IMPCO	$\frac{5.09}{+31.87}$	$\frac{6.25}{+31.03}$	$\frac{8.00}{+16.11}$	$\frac{10.29}{+14.08}$	$\frac{13.25}{+17.36}$
IMPCO + ECI	$\frac{4.85}{+25.64}$	$\frac{6.08}{+27.37}$	$\frac{8.09}{+17.40}$	$\frac{10.58}{+17.26}$	$\frac{12.95}{+14.68}$
BEAM	$\frac{4.66}{+20.77}$	$\frac{5.74}{+20.43}$	$\frac{8.61}{+24.93}$	$\frac{9.94}{+10.21}$	$\frac{12.59}{+11.51}$
A.F.S.	$\frac{4.78}{+23.83}$	$\frac{5.98}{+25.37}$	$\frac{7.71}{+11.90}$	$\frac{9.44}{+4.66}$	$\frac{12.35}{+9.39}$

Table 5-16: Manifold vacuum in. Hg, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE	-	1.04	1.58	2.35	3.29	4.03
	IMPCO	-	1.08	1.41	2.00	2.58	3.14
	IMPCO + ECI	-	1.07	1.40	1.99	2.64	3.20
	BEAM	-	0.68	1.12	1.84	2.47	3.20
	A.F.S.	-	0.67	1.16	1.81	2.71	3.41
66	GASOLINE	-	4.38	4.58	5.48	6.26	7.20
	IMPCO	-	7.70	9.18	10.25	10.37	9.94
	IMPCO + ECI	-	6.37	7.44	8.78	9.88	10.25
	BEAM	-	6.93	7.79	9.32	9.86	10.56
	A.F.S.	-	7.79	8.31	9.37	10.24	10.72
33	GASOLINE	-	13.55	14.38	14.60	14.86	14.90
	IMPCO	-	15.67	16.20	-	18.35	18.37
	IMPCO + ECI	-	15.06	14.78	16.45	17.78	17.69
	BEAM	-	14.99	15.85	16.84	17.19	17.15
	A.F.S.	-	14.85	15.70	16.75	16.78	16.45
∿0	GASOLINE	6.43*	18.44	20.43	22.20	21.77	20.41
	IMPCO	8.00*	19.47	22.20	23.46	22.82	21.93
	IMPCO + ECI	8.72*	19.63	22.68	23.42	22.76	21.27
	BEAM	19.76	21.59	22.21	23.12	22.96	22.34
	A.F.S.	19.07	20.88	21.83	22.67	22.34	21.79

* distributor vacuum

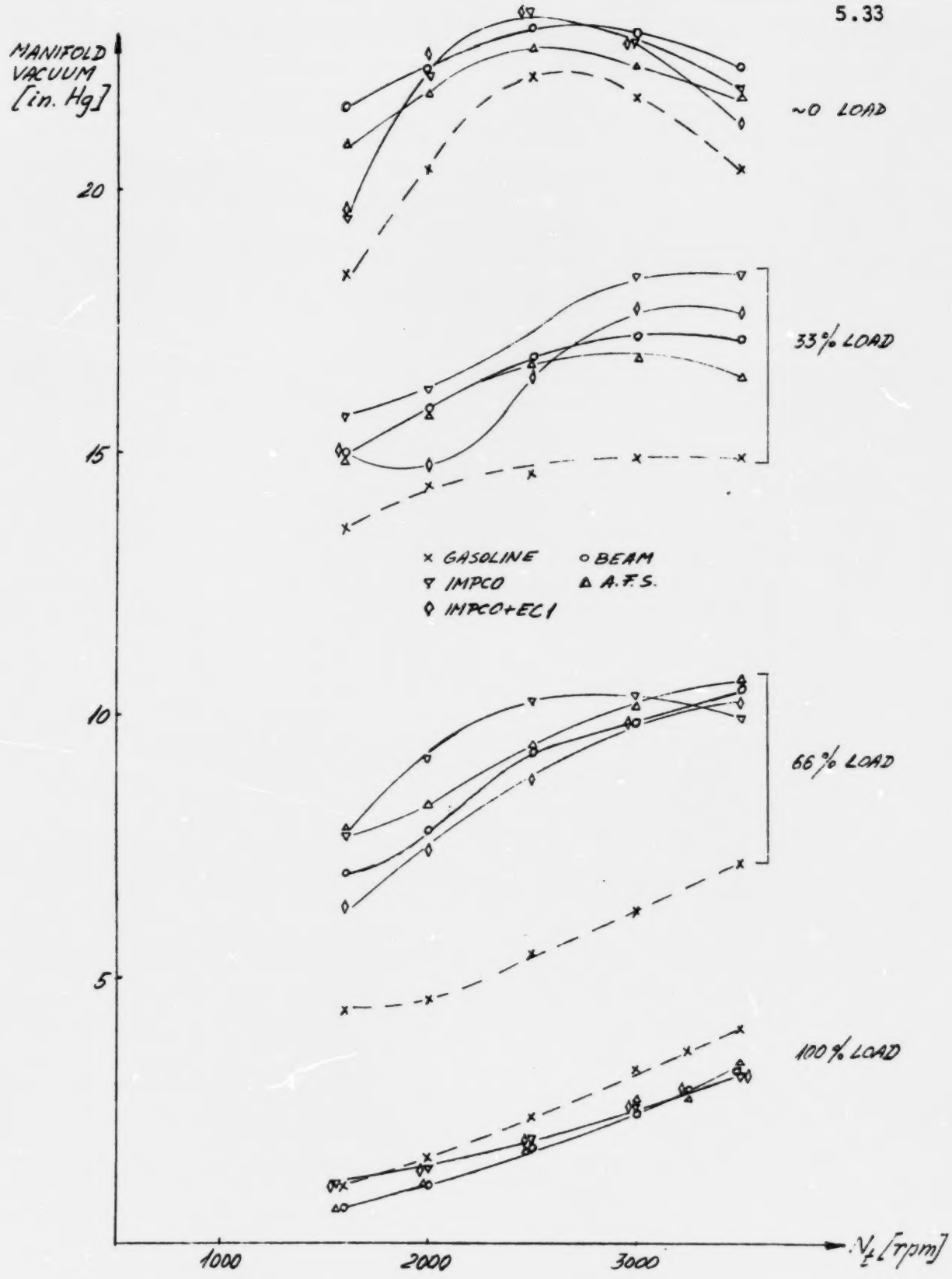


Figure 5-10: Comparison of manifold vacuum

Table 5-17: Total spark advance degrees, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE	-	14.5	15.0	15.5	19.0	21.3
	IMPCO	-	32.1	32.1	31.3	30.3	30.3
	IMPCO + ECI	-	33.0	32.8	32.0	31.8	31.0
	BEAM	-	33.0	33.0	33.0	32.0	32.5
	A.F.S.	-	32.0	31.5	32.0	31.0	29.0
66	GASOLINE	-	21.5	22.8	25.8	29.0	32.0
	IMPCO	-	31.9	32.1	31.4	30.1	30.3
	IMPCO + ECI	-	33.3	33.0	31.8	31.0	31.0
	BEAM	-	33.0	33.0	33.5	32.0	32.0
	A.F.S.	-	32.0	32.0	32.0	31.5	30.0
33	GASOLINE	-	42.3	42.4	42.1	42.4	44.0
	IMPCO	-	32.0	31.9	31.0	30.5	29.5
	IMPCO + ECI	-	32.8	32.8	31.8	31.3	31.0
	BEAM	-	32.5	33.5	33.0	32.0	32.0
	A.F.S.	-	32.0	32.0	31.5	30.5	29.5
∿0	GASOLINE	19.5	42.0	42.4	42.4	42.6	43.8
	IMPCO	13.3	32.0	31.6	31.0	30.1	30.0
	IMPCO + ECI	13.3	32.5	32.5	32.3	32.0	30.8
	BEAM	13.5	33.5	33.5	33.5	32.5	32.0
	A.F.S.	11.5	32.0	32.0	31.5	30.5	30.0

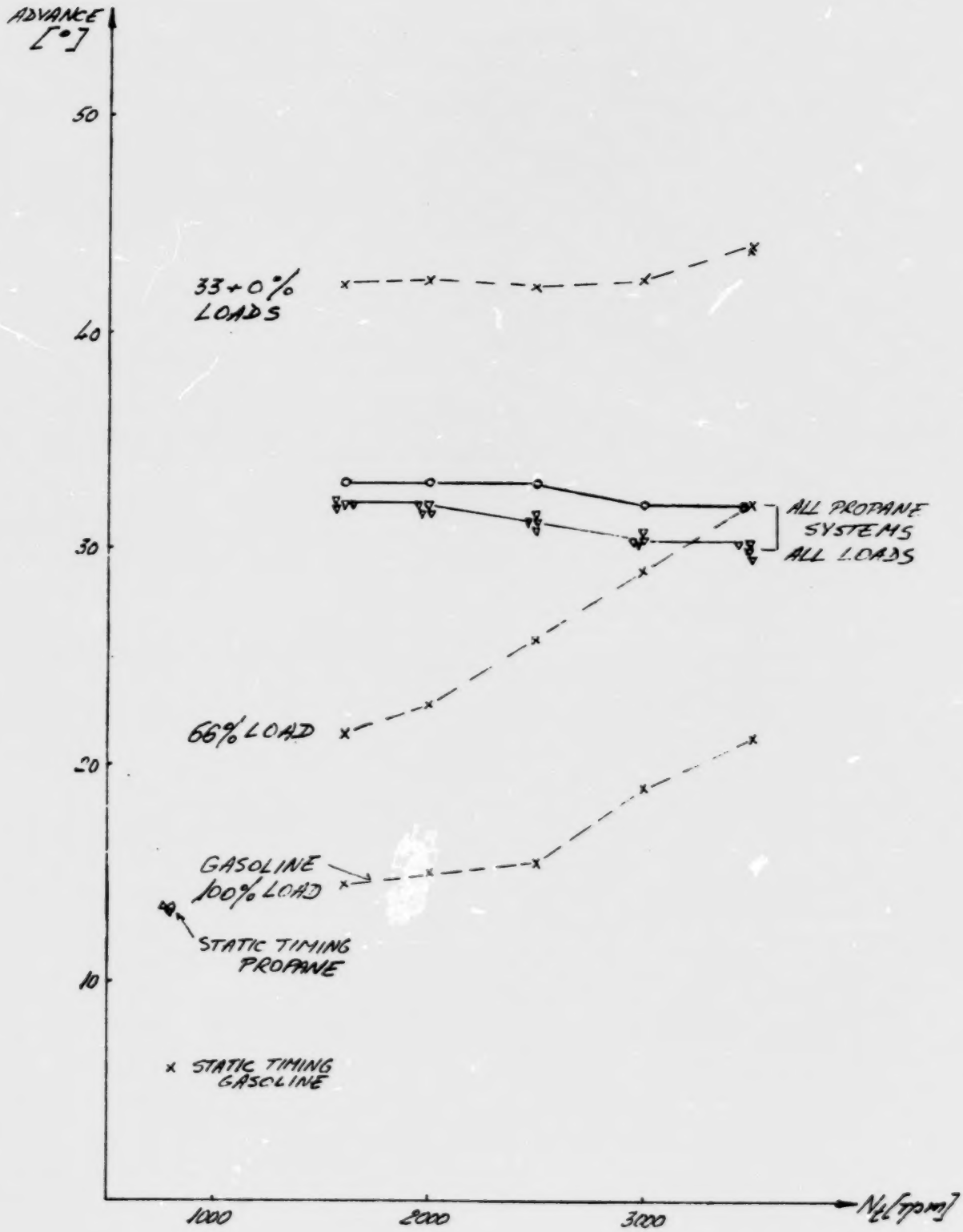


Figure 5-11: Comparison of total spark advance curves

Table 5-18: Throttle position (0-1000 for idle-WOT), average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
66	GASOLINE	-	368	424	454	488	509
	IMPCO	-	274	317	364	420	441
	IMPCO + ECI	-	315	357	402	436	462
	BEAM	-	307	365	409	465	495
	A.F.S.	-	251	310	356	389	411
33	GASOLINE	-	180	211	249	284	315
	IMPCO	-	153	187	230	273	309
	IMPCO + ECI	-	172	202	254	294	324
	BEAM	-	158	203	242	283	315
	A.F.S.	-	136	173	206	245	277
∿0	GASOLINE	000	091	110	145	180	219
	IMPCO	000	052	075	107	153	188
	IMPCO + ECI	000	054	088	126	163	202
	BEAM	000	064	097	117	148	189
	A.F.S.	000	058	075	094	126	158

Table 5-19: Exhaust gas temperature °F, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE	-	1249	1344	1352	1395	1403
	IMPCO	-	1182	1255	1294	1350	1410
	IMPCO + ECI	-	1150	1253	1297	1341	1396
	BEAM	-	1167	1263	1297	1360	1424
	A.F.S.	-	1188	1274	1329	1391	1454
66	GASOLINE	-	1209	1284	1271	1302	1312
	IMPCO	-	1101	1199	1215	1287	1352
	IMPCO + ECI	-	1041	1121	1161	1238	1290
	BEAM	-	1069	1155	1177	1254	1319
	A.F.S.	-	1095	1185	1225	1306	1363
33	GASOLINE	-	991	1066	1053	1129	1180
	IMPCO	-	962	1063	1085	1176	1248
	IMPCO + ECI	-	942	1011	1036	1108	1175
	BEAM	-	957	1043	1062	1141	1207
	A.F.S.	-	958	1047	1090	1176	1245
∿0	GASOLINE	593	813	870	868	999	1077
	IMPCO	632	805	871	875	988	1077
	IMPCO + ECI	640	783	879	877	954	1041
	BEAM	633	810	864	870	955	1043
	A.F.S.	638	819	875	871	968	1075

- measured before catalytic converter, at the end of the 3 min. test period.

- from 2500 rpm with forced ventilation of exhaust manifold.

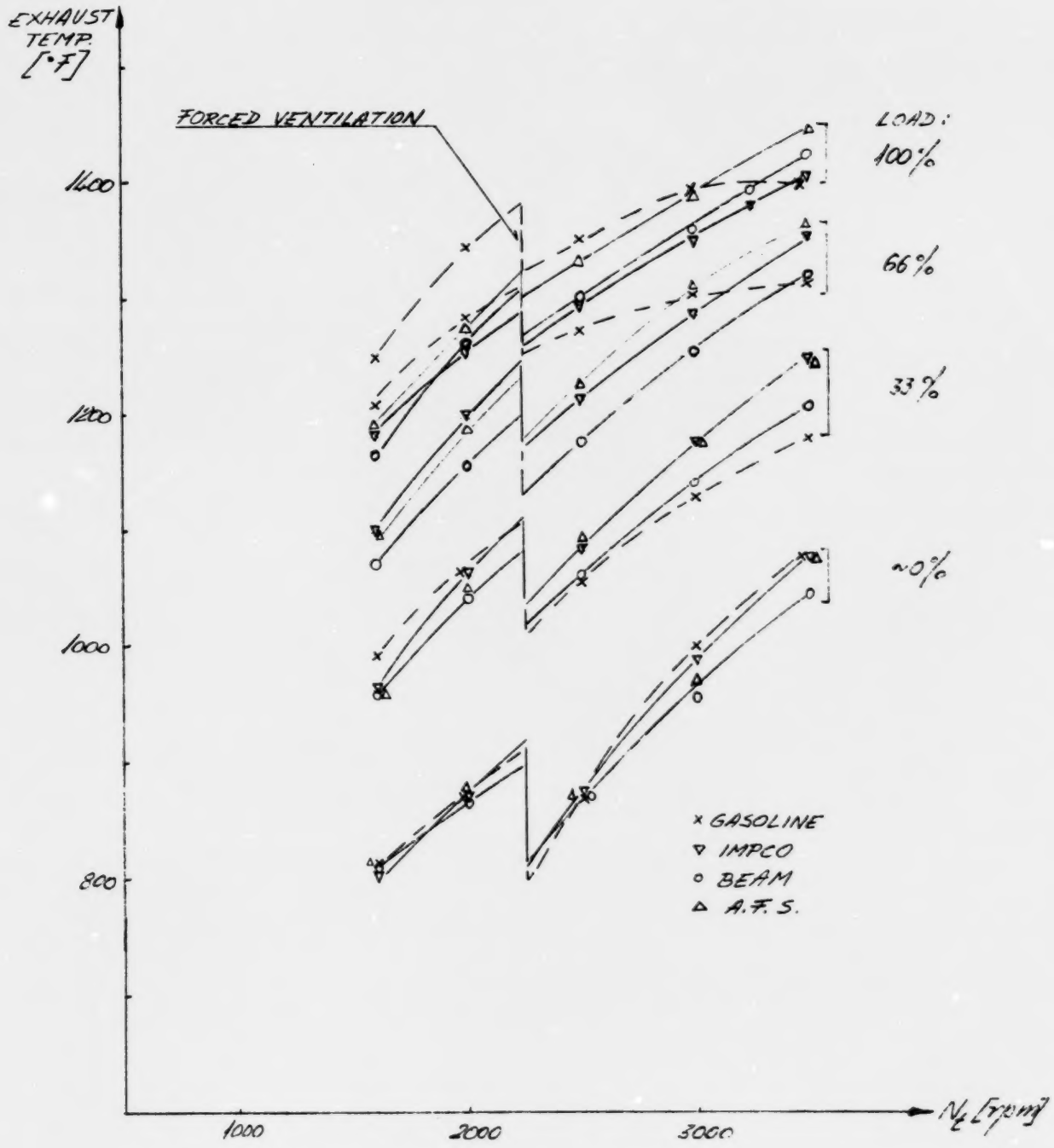


Figure 5-12: Comparison of exhaust gas temperatures

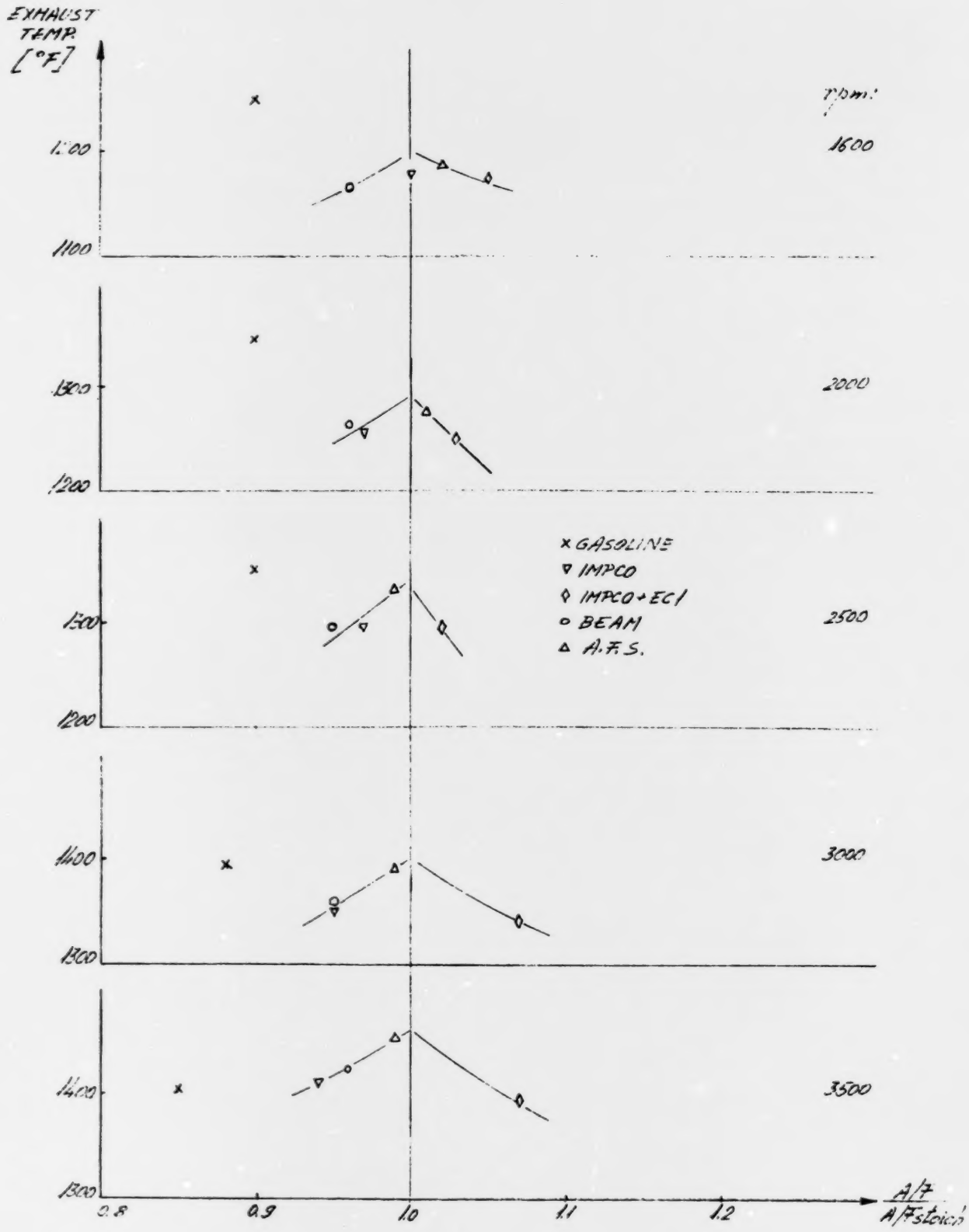


Figure 5-13: Correlation between exhaust gas temperature and A/F ratio - 100% load

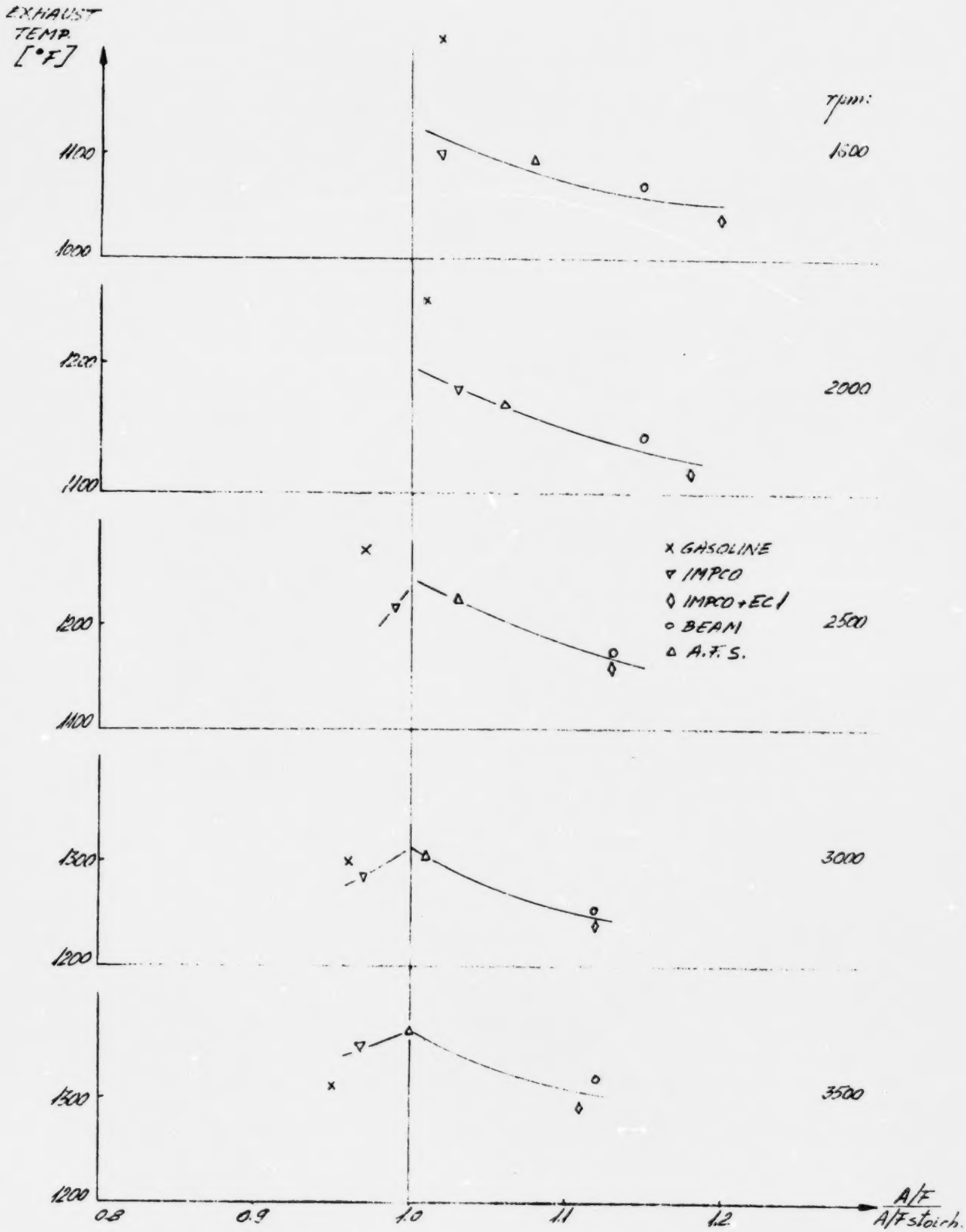


Figure 5-14: Correlation between exhaust gas temperature and A/F ratio - 66% load

Table 5-20: Distribution of cylinders exhaust gas temperature - ^{o}F

Engine speed: 1600 rpm, average values

Load [%]	Carburetion System	Cylinder number					
		1	2	3	4	5	6
100	GASOLINE	1280	1323	1355	1439	1337	1312
	IMPCO	1240	1271	1257	1351	1294	1298
	IMPCO + ECI	1224	1244	1239	1308	1249	1263
	BEAM	1236	1238	1229	1332	1273	1285
	A.F.S.	1237	1268	1267	1355	1295	
66	GASOLINE	1275	1303	1321	1402	1365	1358
	IMPCO	1192	1219	1215	1295	1245	1250
	IMPCO + ECI	1123	1145	1144	1219	1175	1180
	BEAM	1138	1169	1164	1235	1191	1185
	A.F.S.	1185	1203	1200	1280	1240	
33	GASOLINE	1164	1179	1179	1245	1247	1249
	IMPCO	1135	1157	1148	1195	1194	1198
	IMPCO + ECI	1100	1119	1110	1158	1152	1161
	BEAM	1115	1138	1121	1154	1160	1169
	A.F.S.	1121	1134	1135	1168	1175	
∿0	GASOLINE	1027	1077	1051	1126	1138	1126
	IMPCO	999	1048	1017	1096	1135	1127
	IMPCO + ECI	1006	1054	999	1069	1126	1143
	BEAM	1028	1061	1046	1079	1106	1134
	A.F.S.	1050	1078	1095	1107	1145	

- measured in the middle of the exhaust manifold ports, at 1 in. from exhaust valve steam.

Table 5-21: Distribution of cylinders exhaust gas temperature - ^{o}F

Engine speed: 2500 rpm, average values

Load [%]	Carburetion System	Cylinder number					
		1	2	3	4	5	6
100	GASOLINE	1440	1486	1501	1593	1526	1468
	IMPCO	1378	1403	1384	1500	1452	1427
	IMPCO + ECI	1416	1432	1418	1478	1427	1412
	BEAM	1409	1376	1379	1486	1432	1404
	A.F.S.	1436	1428	1442	1514	1452	1426
66	GASOLINE	1391	1424	1412	1529	1499	1494
	IMPCO	1370	1393	1381	1455	1413	1386
	IMPCO + ECI	1310	1322	1323	1388	1350	1326
	BEAM	1312	1333	1323	1379	1340	1305
	A.F.S.	1380	1387	1382	1455	1415	1385
33	GASOLINE	1311	1344	1315	1388	1378	1374
	IMPCO	1321	1337	1331	1389	1363	1349
	IMPCO + ECI	1249	1271	1261	1305	1295	1278
	BEAM	1276	1296	1282	1322	1310	1302
	A.F.S.	1322	1329	1330	1374	1357	1352
∿0	GASOLINE	1265	1290	1284	1332	1359	1343
	IMPCO	1173	1175	1198	1237	1270	1300
	IMPCO + ECI	1175	1206	1209	1230	1270	1300
	BEAM	1166	1192	1185	1188	1234	1277
	A.F.S.	1178	1173	1187	1190	1247	1277

- measured in the middle of the exhaust manifold ports, at 1 in. from exhaust valve steam.

Table 5-22: Distribution of cylinders exhaust gas temperature - ^{o}F

Engine speed: 3500 rpm, average values

Load [%]	Carburetion System	Cylinder number					
		1	2	3	4	5	6
100	GASOLINE	1487	1522	1535	1632	1573	1559
	IMPCO	1483	1521	1486	1629	1582	1610
	IMPCO + ECI	1532	1548	1552	1564	1524	1550
	BEAM	1532	1483	1506	1598	1542	1558
	A.F.S.	1566	1578	1582	1631	1580	1616
66	GASOLINE	1449	1484	1442	1561	1539	1571
	IMPCO	1491	1512	1507	1579	1533	1562
	IMPCO + ECI	1428	1455	1450	1521	1481	1521
	BEAM	1436	1481	1472	1511	1491	1498
	A.F.S.	1518	1534	1531	1587	1549	1577
33	GASOLINE	1415	1437	1433	1479	1483	1504
	IMPCO	1457	1476	1474	1532	1510	1550
	IMPCO + ECI	1371	1386	1383	1438	1423	1473
	BEAM	1392	1417	1416	1446	1437	1482
	A.F.S.	1459	1473	1476	1516	1501	1541
∿0	GASOLINE	1366	1397	1397	1424	1456	1501
	IMPCO	1341	1392	1402	1411	1424	1447
	IMPCO + ECI	1294	1343	1341	1359	1370	1413
	BEAM	1329	1375	1356	1337	1361	1430
	A.F.S.	1386	1396	1403	1397	1403	1480

- measured in the middle of the exhaust manifold ports, at 1 in. from exhaust valve steam.

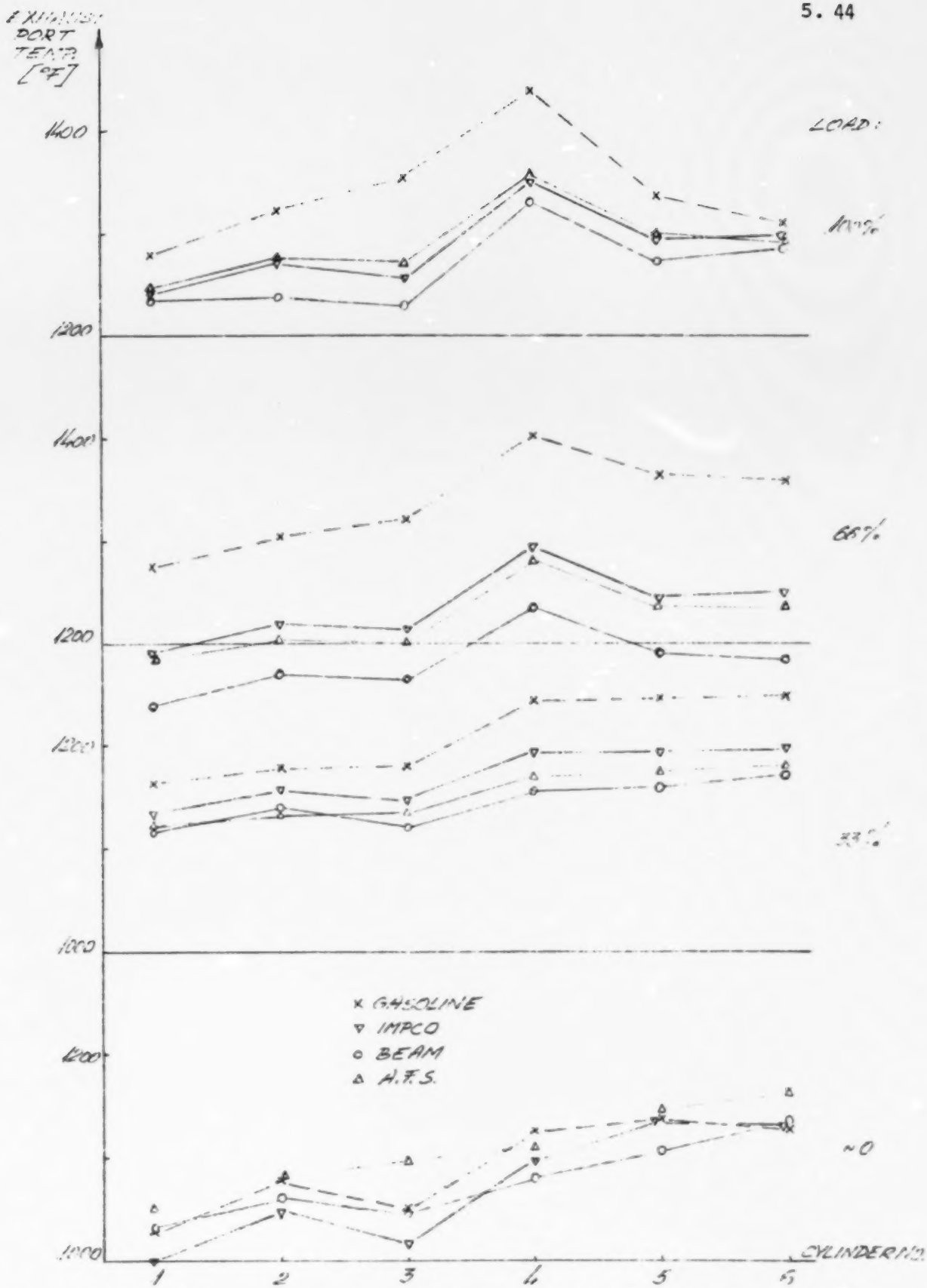


Figure 5-15: Temperature of exhaust gas from each cylinder at 1600 rpm

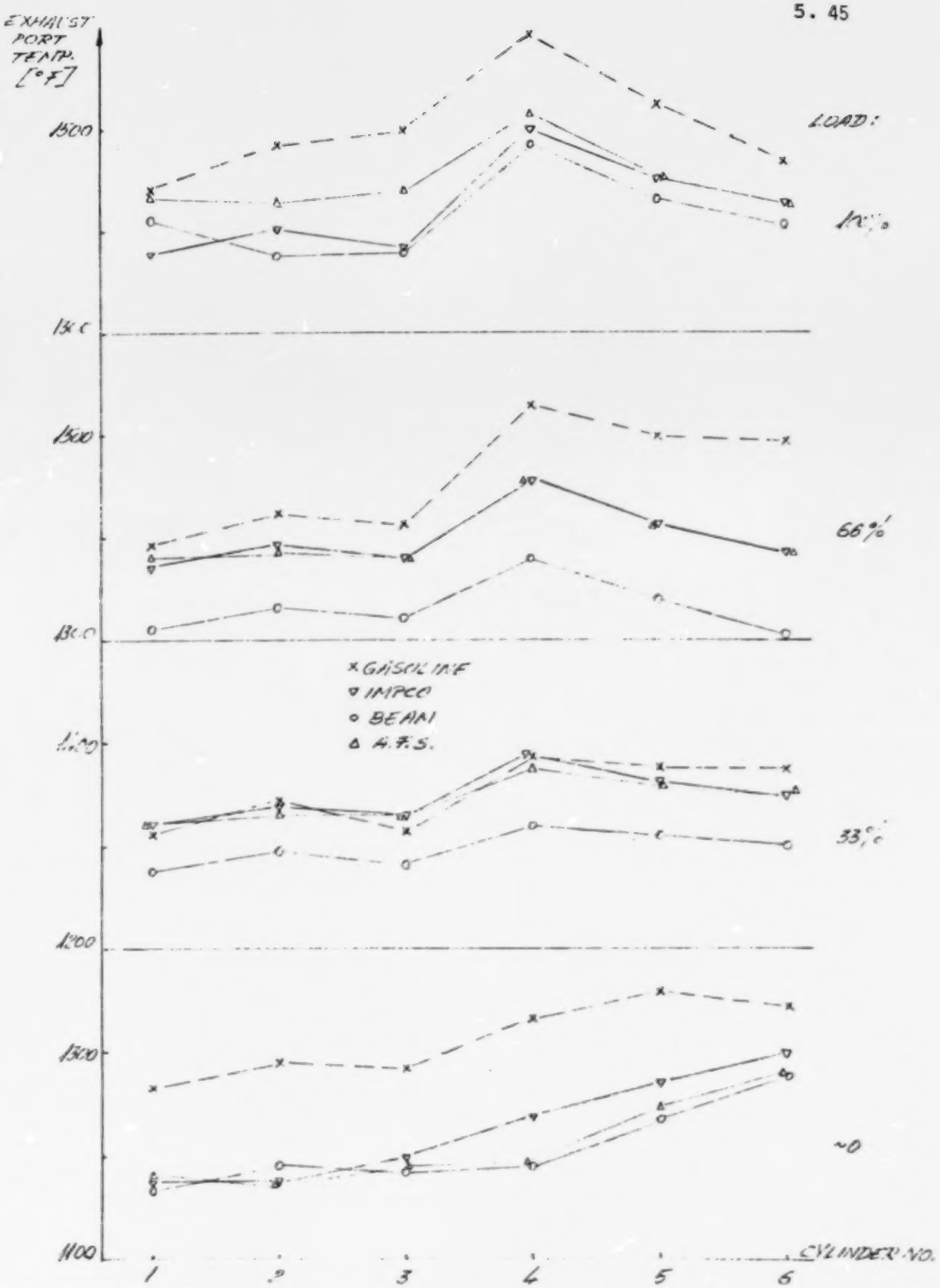


Figure 5-16: Temperature of exhaust gas from each cylinder at 2500 rpm

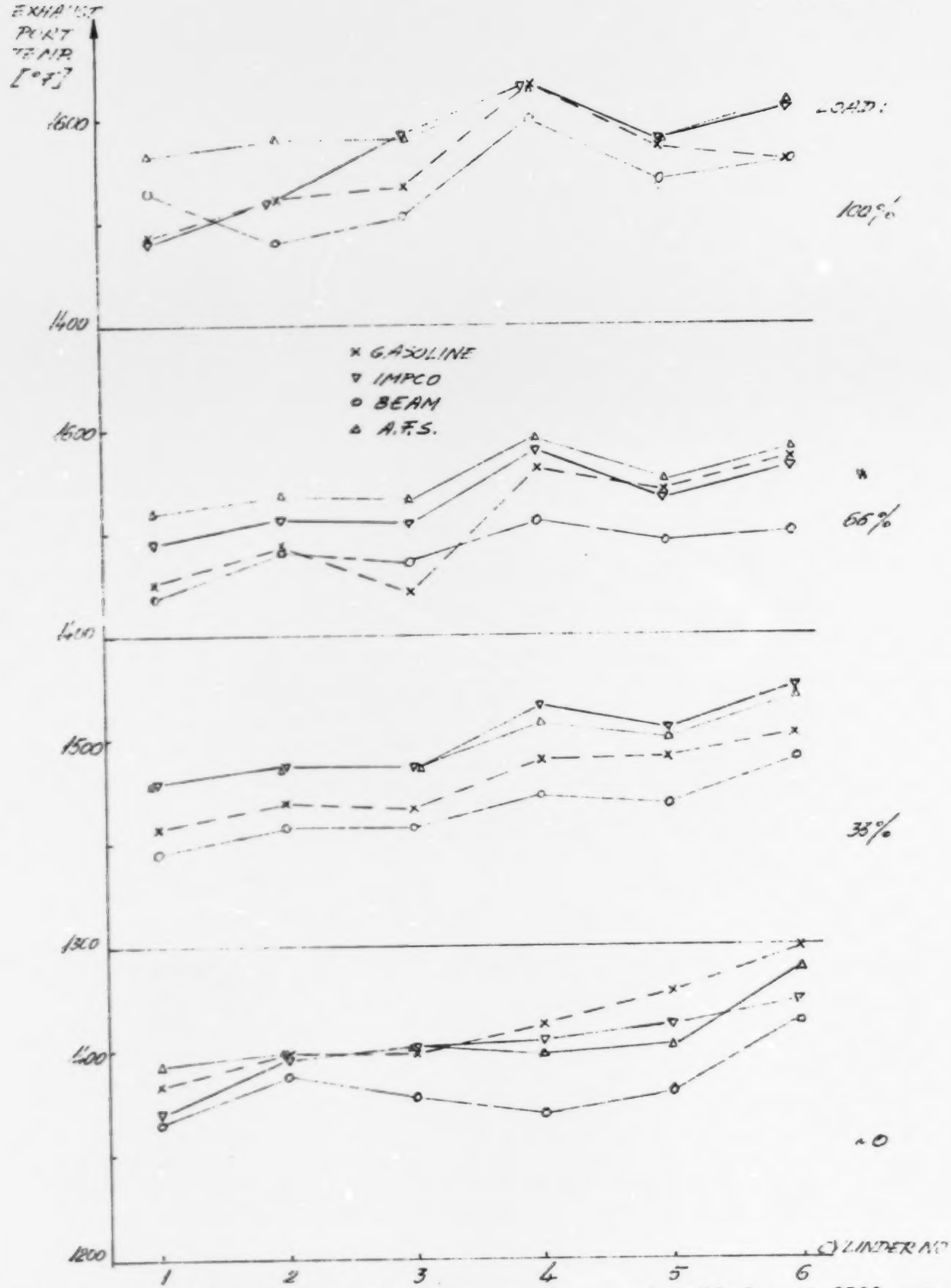


Figure 5-17: Temperature of exhaust gas from each cylinder at 3500 rpm

Table 5-23: HC Emission

PPM, average values

Load [%]	Carburetion System	Engine speed [rpm]				
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		100	92	66	61	63
	IMPCO		106	100	73	58	58
	IMPCO + ECI		73	67	49	32	24
	BEAM		97	89	63	46	29
	A.F.S.		73	72	61	49	43
66	GASOLINE		61	54	57	59	58
	IMPCO		77	69	71	70	67
	IMPCO + ECI		66	51	38	31	25
	BEAM		66	50	39	32	20
	A.F.S.		75	53	44	41	37
33	GASOLINE		98	77	56	53	61
	IMPCO		53	40	27	31	26
	IMPCO + ECI		52	38	28	26	22
	BEAM		51	35	27	24	18
	A.F.S.		52	40	31	25	19
∿0	GASOLINE	395	94	87	72	52	53
	IMPCO	77	24	15	12	16	16
	IMPCO + ECI	120	40	31	26	22	20
	BEAM	118	44	21	13	13	12
	A.F.S.	97	50	22	15	13	13

- before catalytic converter; gasoline with emission controls, propane without.

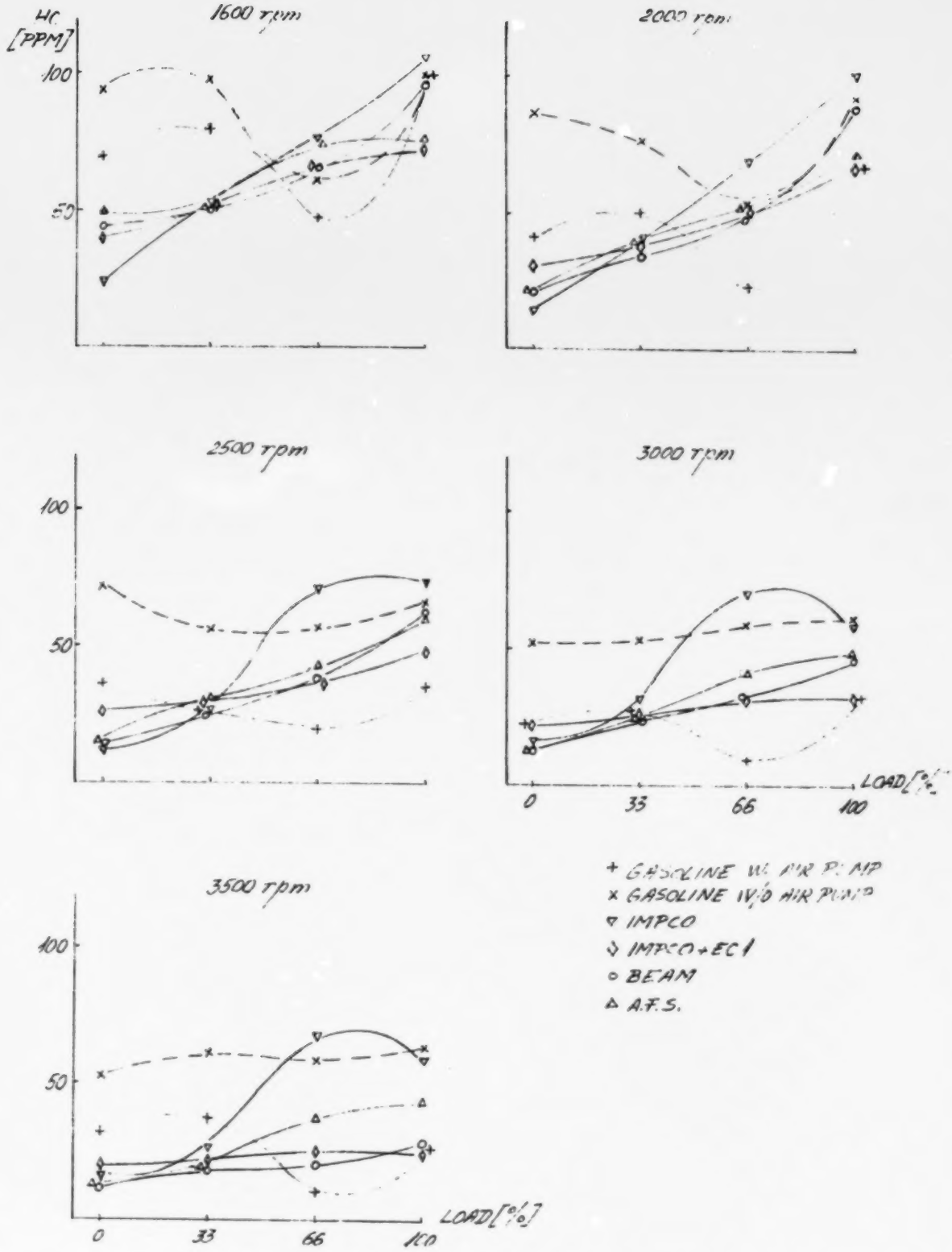


Figure 5-18: HC emission at different loads and speeds - before catalytic converter (gasoline with emission controls, propane without)

Table 5-24: CO Emission

%, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		4.14	3.90	4.03	4.59	5.59
	IMPCO		0.40	1.06	1.40	1.94	2.23
	IMPCO + ECI		0.08	0.14	0.38	0.18	0.20
	BEAM		1.66	1.71	1.98	2.05	2.09
	A.F.S.		0.12	0.20	0.51	0.63	0.72
66	GASOLINE		0.35	0.53	1.32	1.93	2.00
	IMPCO		0.10	0.15	0.61	1.00	1.23
	IMPCO + ECI		0.08	0.09	0.10	0.11	0.12
	BEAM		0.10	0.10	0.11	0.11	0.13
	A.F.S.		0.11	0.12	0.13	0.25	0.41
33	GASOLINE		0.30	0.29	0.27	0.33	0.78
	IMPCO		0.12	0.13	0.15	0.18	0.21
	IMPCO + ECI		0.11	0.11	0.12	0.13	0.13
	BEAM		0.11	0.12	0.12	0.14	0.14
	A.F.S.		0.13	0.12	0.15	0.16	0.18
∿0	GASOLINE	0.36	0.62	0.99	1.05	0.67	0.76
	IMPCO	0.16	0.19	0.18	0.16	0.16	0.16
	IMPCO + ECI	0.13	0.18	0.18	0.18	0.18	0.16
	BEAM	1.34	0.20	0.18	0.16	0.16	0.16
	A.F.S.	0.66	0.20	0.18	0.17	0.17	0.17

- before catalytic converter; gasoline with emission controls, propane without.

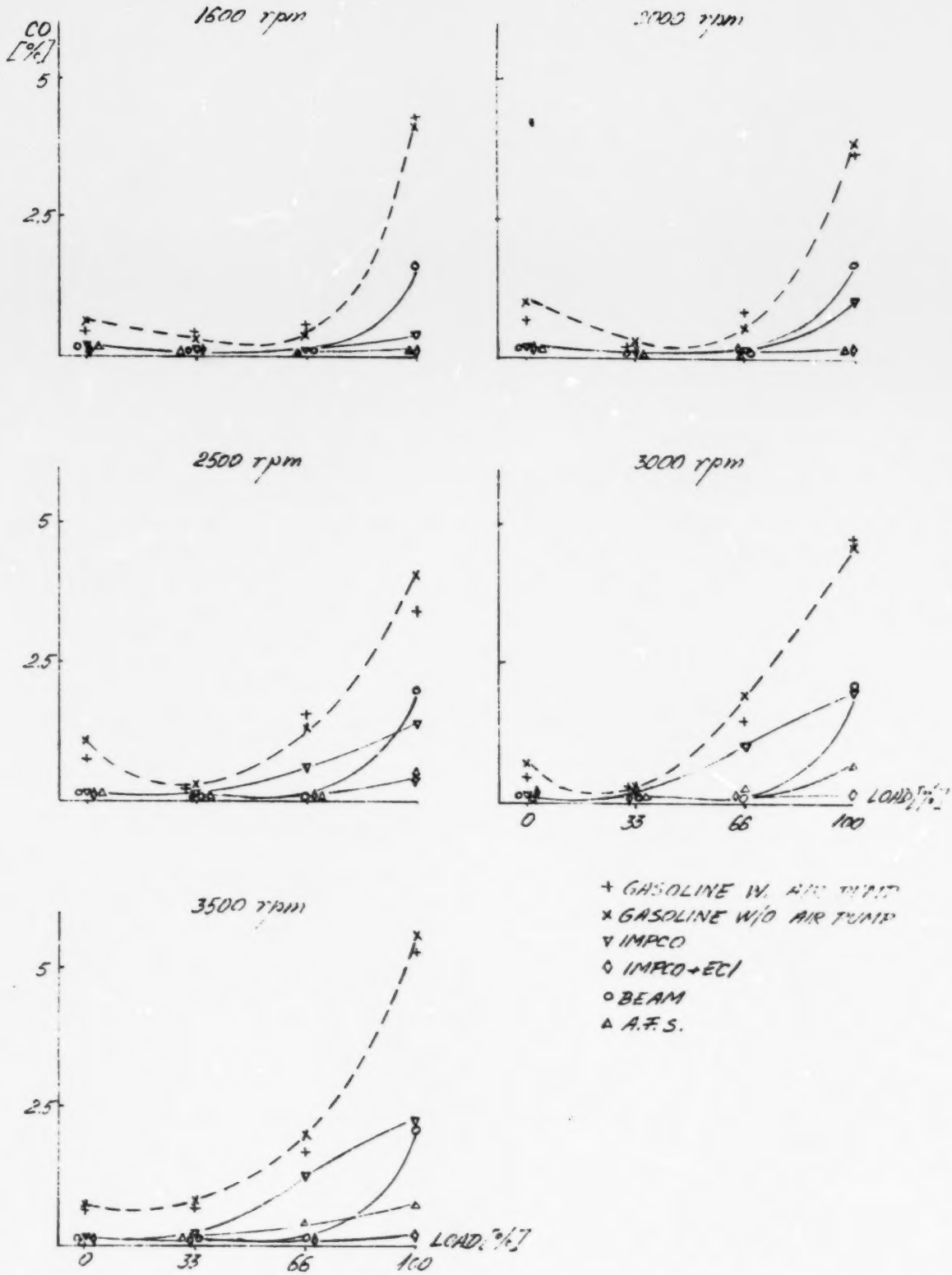


Figure 5-19: CO emission at different loads and speeds - before catalytic converter (gasoline with emission controls, propane without)

Table 5-25: CO_2 Emission
%, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		12.98	13.05	13.00	12.30	11.85
	IMPCO		13.23	12.82	12.45	12.10	11.80
	IMPCO + ECI		12.80	12.80	12.50	11.85	12.15
	BEAM		12.20	12.10	11.90	11.90	11.60
	A.F.S.		12.90	12.80	12.90	12.80	12.70
66	GASOLINE		15.33	14.83	14.90	14.53	14.35
	IMPCO		12.97	13.03	13.00	12.50	12.47
	IMPCO + ECI		11.10	11.03	11.45	11.50	11.60
	BEAM		11.10	11.20	11.40	11.50	11.40
	A.F.S.		12.30	12.10	12.70	13.00	12.70
33	GASOLINE		15.30	15.13	15.03	14.98	14.95
	IMPCO		12.67	12.57	12.73	12.67	12.73
	IMPCO + ECI		10.70	10.85	10.75	10.75	11.05
	BEAM		11.00	11.10	11.50	11.50	11.40
	A.F.S.		10.90	11.40	12.50	12.60	12.50
∿0	GASOLINE	14.28	15.13	15.05	14.88	15.10	15.05
	IMPCO	12.70	12.63	11.93	11.83	11.92	12.17
	IMPCO + ECI	11.25	11.20	10.45	10.00	10.15	10.65
	BEAM	12.25	10.70	10.90	11.60	11.70	11.50
	A.F.S.	11.30	10.50	10.50	11.70	11.80	11.80

- before catalytic converter; gasoline with emission controls, propane without.

Table 5-26: O_2 Emission
%, average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		0.27	0.20	0.19	0.18	0.16
	IMPCO		0.32	0.21	0.23	0.24	0.21
	IMPCO + ECI		1.08	0.80	0.69	1.48	1.45
	BEAM		0.23	0.30	0.34	0.41	0.45
	A.F.S.		0.59	0.44	0.20	0.21	0.18
66	GASOLINE		0.68	0.67	0.35	0.26	0.28
	IMPCO		0.97	0.56	0.19	0.16	0.18
	IMPCO + ECI		3.78	3.33	2.60	2.35	2.15
	BEAM		2.95	2.80	2.43	2.38	2.35
	A.F.S.		1.68	1.30	0.66	0.34	0.27
33	GASOLINE		0.70	0.77	0.86	0.80	0.51
	IMPCO		1.81	1.28	0.92	0.69	0.56
	IMPCO + ECI		4.40	3.95	3.73	3.48	3.15
	BEAM		3.20	3.13	2.48	2.58	2.50
	A.F.S.		3.53	2.80	1.68	1.08	0.85
∿0	GASOLINE	1.56	0.81	0.49	0.46	0.53	0.50
	IMPCO	1.37	1.34	2.12	2.20	1.89	1.48
	IMPCO + ECI	3.05	3.23	4.58	4.73	4.53	3.88
	BEAM	0.44	3.63	3.65	2.53	2.38	2.55
	A.F.S.	2.43	5.60	4.55	2.73	2.83	2.08

- before catalytic converter; gasoline with emission controls, propane without.

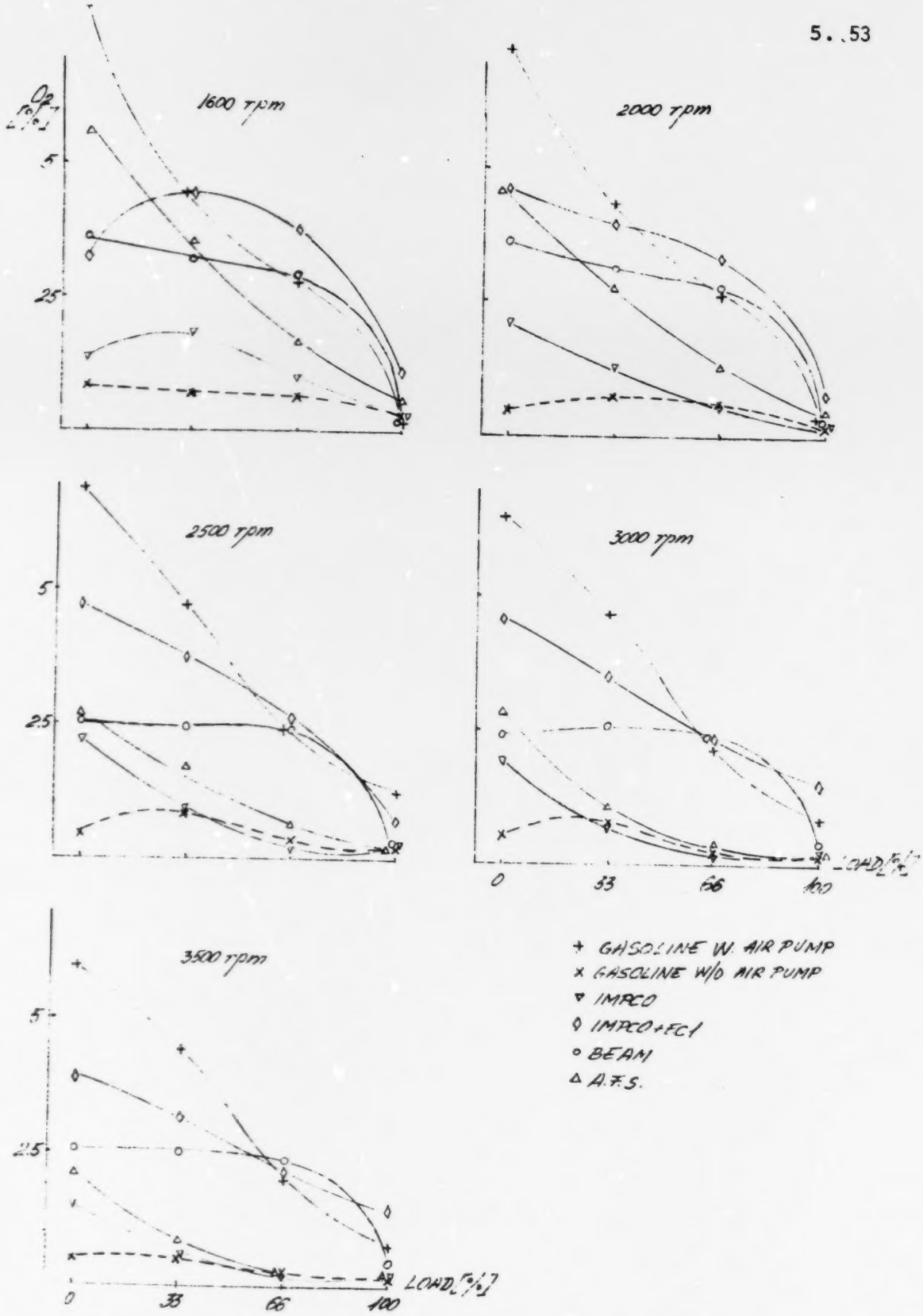


Figure 5-20: O_2 emission at different loads and speeds - before catalytic converter (gasoline with emission controls, propane without)

Table 5-27: NO Emission
PPM, average values

Load [%]	Carburetion System	Engine speed [rpm]				
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		1010	1160	1130	1050	905
	IMPCO		3680	3270	2980	2820	2550
	IMPCO + ECI		4850	4450	4150	4400	4550
	BEAM		2675	2900	2875	3025	3025
	A.F.S.		4175	4175	3800	3900	3750
66	GASOLINE		1270	1240	980	1110	1380
	IMPCO		4070	3980	3330	3200	3070
	IMPCO + ECI		3450	3650	3950	4000	4100
	BEAM		4100	4200	4125	4300	4100
	A.F.S.		4075	4275	4050	3800	3625
33	GASOLINE		960	1190	1140	1480	1620
	IMPCO		2230	2620	2650	2950	2880
	IMPCO + ECI		950	1080	1470	1770	2130
	BEAM		1630	1845	2425	2800	2650
	A.F.S.		1685	2275	2775	2985	2850
∿0	GASOLINE	42	157	273	190	300	646
	IMPCO	15	59	84	166	390	710
	IMPCO + ECI	5	20	20	36	104	280
	BEAM	33	14	31	155	350	530
	A.F.S.	22	14	38	176	360	625

- before catalytic converter; gasoline with emission controls, propane without.

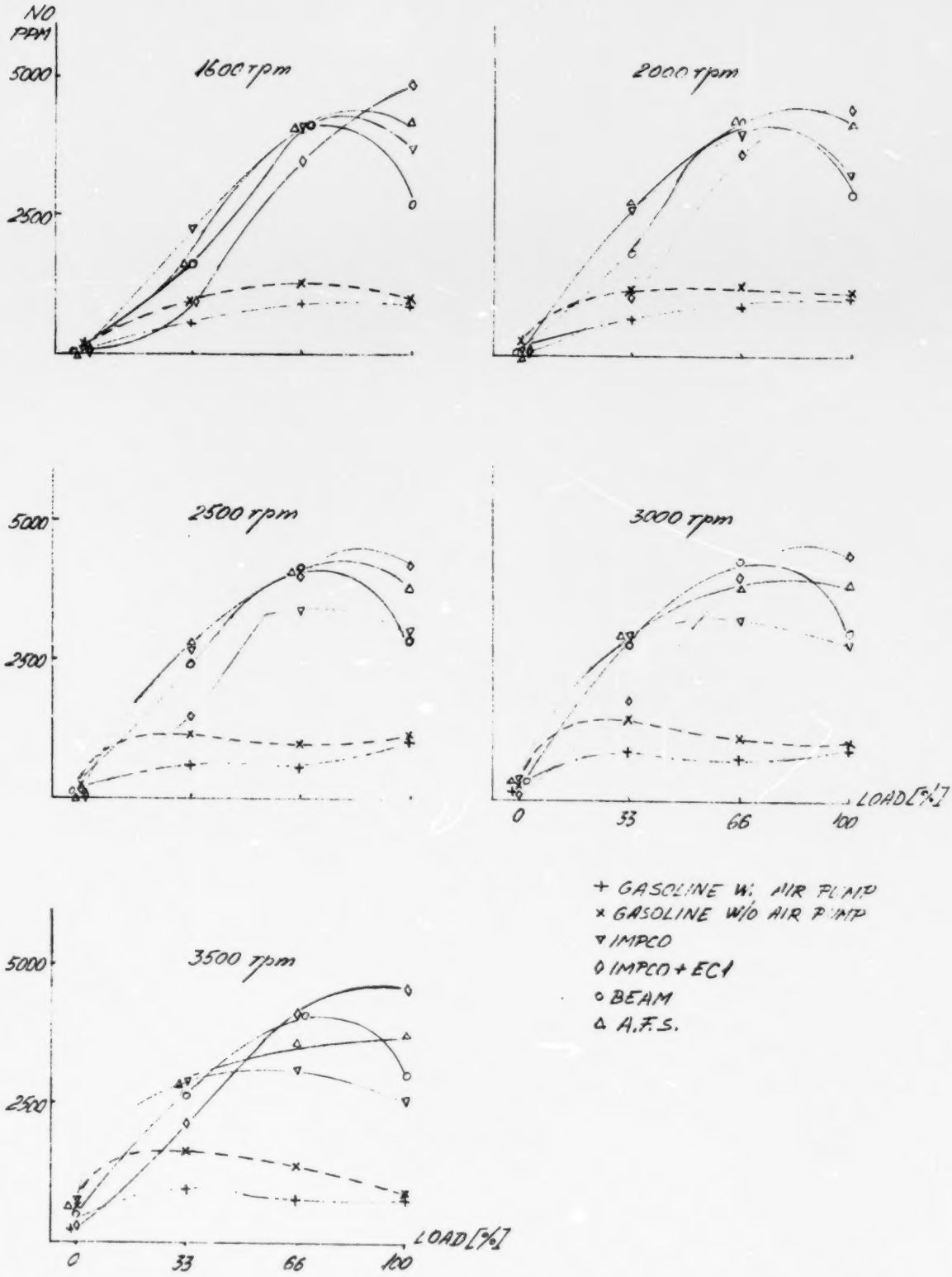


Figure 5-21: NO emission at different loads and speeds - before catalytic converter (gasoline with emission controls, propane without)

Table 5-28: Emissions for gasoline carburetion system, with air pump active

PARAM.		U.M.	VALUES					
SPEED		rpm	IDLE 600	1580	2000	2500	3000	3500
100%/LOAD	HC	PPM		100	67	35	30	26
	CO	%		4.3	3.7	3.4	4.75	5.30
	CO_2	%		12.7	12.5	12.0	11.5	10.9
	O_2	%		0.15	0.35	1.25	0.85	0.75
	NO	PPM		900	1100	1040	920	850
2/3 LOAD	HC	PPM		48	23	20	9	10
	CO	%		0.55	0.83	1.55	1.45	1.70
	CO_2	%		12.9	13.0	12.7	12.5	12.6
	O_2	%		2.8	2.65	2.35	2.15	2.00
	NO	PPM		900	900	560	770	780
1/3 LOAD	HC	PPM		80	50	27	26	37
	CO	%		0.40	0.19	0.22	0.30	0.63
	CO_2	%		11.7	12.0	11.5	11.5	11.2
	O_2	%		4.4	4.35	4.70	4.65	4.40
	NO	PPM		550	670	690	880	950
(∿0) LOAD	HC	PPM	250	70	41	36	22	32
	CO	%	1.0	0.44	0.70	0.77	0.45	0.70
	CO_2	%	13.5	9.0	9.4	9.7	10.0	10.1
	O_2	%	0.70	8.1	7.3	6.9	6.45	6.00
	NO	PPM	45	75	60	70	135	200

Table 5-29: Air-fuel ratio (A/F stoichiometric ≈14.59 for gasoline, ≈15.69 for propane), average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		13.09	13.14	13.10	12.89	12.39
	IMPCO		15.66	15.28	15.15	14.92	14.75
	IMPCO + ECI		16.43	16.20	16.02	16.78	16.73
	BEAM		14.99	15.03	14.96	14.99	15.01
	A.F.S.		16.05	15.91	15.59	15.55	15.49
66	GASOLINE		14.81	14.74	14.22	13.94	13.93
	IMPCO		16.02	16.18	15.50	15.29	15.20
	IMPCO + ECI		18.80	18.44	17.77	17.57	17.39
	BEAM		18.12	17.99	17.66	17.62	17.61
	A.F.S.		16.88	16.66	16.14	15.84	15.71
33	GASOLINE		14.79	14.88	14.97	14.91	14.65
	IMPCO		16.91	16.56	16.29	16.11	16.00
	IMPCO + ECI		19.36	18.97	18.82	18.61	18.27
	BEAM		18.25	18.21	17.63	17.72	17.68
	A.F.S.		18.57	17.90	16.88	16.43	16.25
∿0	GASOLINE	15.02	14.72	14.40	14.35	14.57	14.52
	IMPCO	16.47	16.49	17.16	17.25	17.01	16.68
	IMPCO + ECI	17.88	18.13	19.51	19.82	19.61	18.89
	BEAM	15.16	18.55	18.60	18.57	17.43	17.61
	A.F.S.	17.02	20.76	19.52	17.75	17.83	17.13

Table 5-30: Equivalence air-fuel ratio ($\frac{A/F}{A/F\ stoich}$) average values

Load [%]	Carburetion System	Engine speed [rpm]					
		600 gas. / 700 pr.	1600	2000	2500	3000	3500
100	GASOLINE		0.90	0.90	0.90	0.88	0.85
	IMPCO		1.00	0.97	0.97	0.95	0.94
	IMPCO + ECI		1.05	1.03	1.02	1.07	1.07
	BEAM		0.96	0.96	0.95	0.95	0.96
	A.F.S.		1.02	1.01	0.99	0.99	0.99
66	GASOLINE		1.02	1.01	0.97	0.96	0.95
	IMPCO		1.02	1.03	0.99	0.97	0.97
	IMPCO + ECI		1.20	1.18	1.13	1.12	1.11
	BEAM		1.15	1.15	1.13	1.12	1.12
	A.F.S.		1.08	1.06	1.03	1.01	1.00
33	GASOLINE		1.01	1.02	1.03	1.02	1.00
	IMPCO		1.08	1.06	1.04	1.03	1.02
	IMPCO + ECI		1.23	1.21	1.20	1.19	1.16
	BEAM		1.16	1.16	1.12	1.13	1.13
	A.F.S.		1.18	1.14	1.08	1.05	1.04
∿0	GASOLINE	1.03	1.01	0.97	0.98	1.00	1.00
	IMPCO	1.05	1.05	1.09	1.10	1.08	1.06
	IMPCO + ECI	1.14	1.16	1.24	1.26	1.25	1.20
	BEAM	0.97	1.18	1.19	1.18	1.11	1.12
	A.F.S.	1.08	1.32	1.24	1.13	1.14	1.09

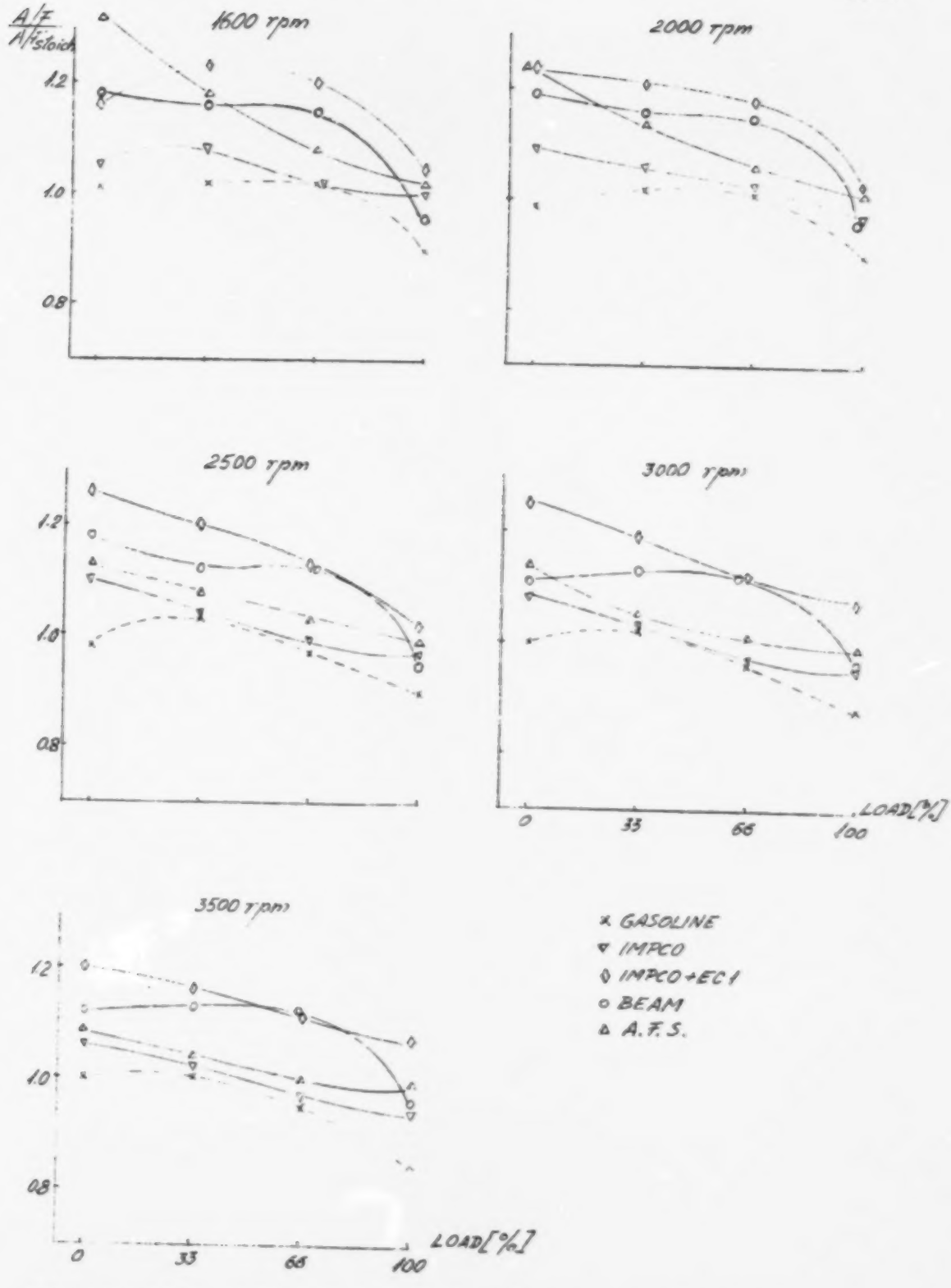


Figure 5-22: Air-fuel ratio at different loads and speeds

6. SYSTEM OPTIMIZATION

6.1 PROCEDURE

The influence of timing and air-fuel ratio is analyzed according to the procedure described here, for full and partial loads.

6.1.1 Influence of timing at full load (WOT) - see Figure 6-1:

- set ignition manually, isolating the vacuum advance and moving the body of the distributor until the desired timing angle is read
- stabilize on lowest desired speed with spark retarded from the best torque timing
- record torque and timing
- advance spark 3 degrees and record torque, maintaing the speed constant
- repeat until a 3-degree advance shows no improvement in torque
- retard half interval, check that torque and speed are unchanged, run and record data at determined minimum for best torque (MBT) advance
- repeat in speed increments to maximum test speed

6.1.2 Influence of air-fuel ratio at full load (WOT) - see Figure 6-2:

- adjust carburetion system, controlling the reference pressure in the second stage of

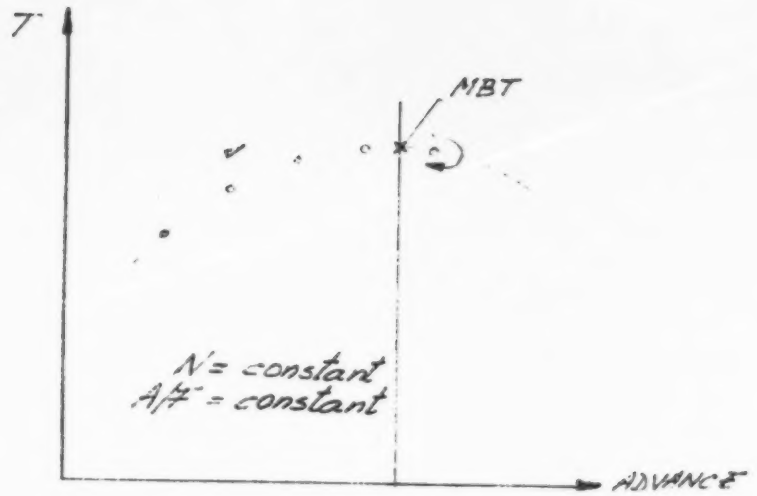


Figure 6-1: Principle of Timing Optimization at Full Load, for MBT (minimum for best torque)

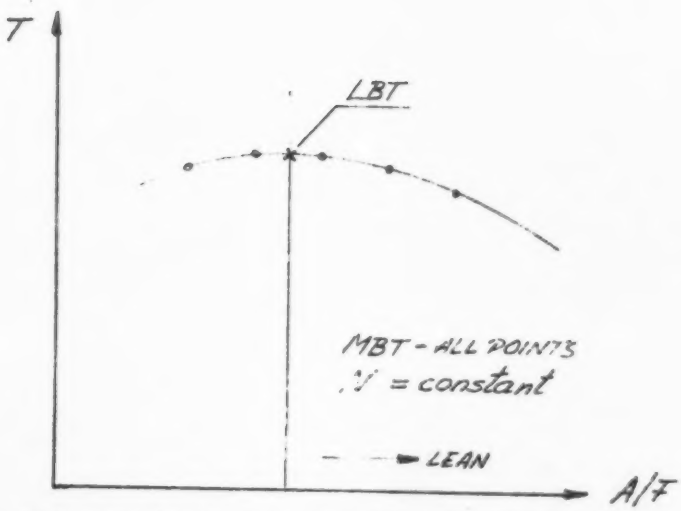


Figure 6-2: Principle of Air-Fuel Ratio Optimization at Full Load, for LBT (leanest for best torque)

regulator (IMPCO) or the opening of power valve between vaporizer/regulator and carburettor

- set ignition manually as in 6.1.1
- stabilize at lowest desired speed with the carburetion system richer than leanest for best torque (LBT) and spark retarded from MBT setting
- record torque, timing and A/F ratio
- determine and record MBT timing at constant A/F ratio, as per 6.1.1
- lean air-fuel mixture
- readjust and record MBT timing and new A/F ratio
- record torque
- lean air-fuel mixture and readjust MBT timing until torque falls below previous value
- adjust mixture richer, midway between last two settings and readjust MBT timing
- check that torque is equal to previous maximum value and speed is unchanged, run and record data at determined LBT
- repeat in speed increments to maximum test speed

6.1.3 Influence of timing at partial loads (2/3 and 1/3 of maximum at WOT) - see Figure 6-3

- set ignition manually
- stabilize at lowest desired speed, 2/3 or 1/3 of the MBT torque, with spark retarded from the point of minimum specific fuel consumption
- run the test and compute BSFC

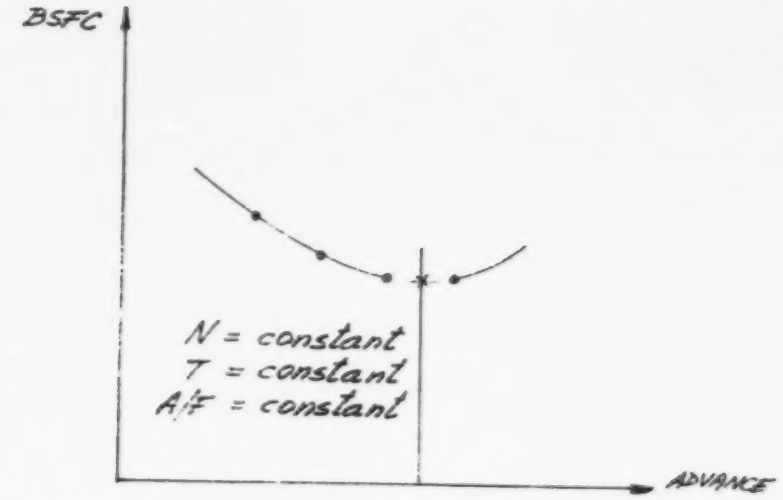


Figure 6-3: Principle of Timing Optimization at Partial Loads, for Minimum BSFC (brake specific fuel consumption)

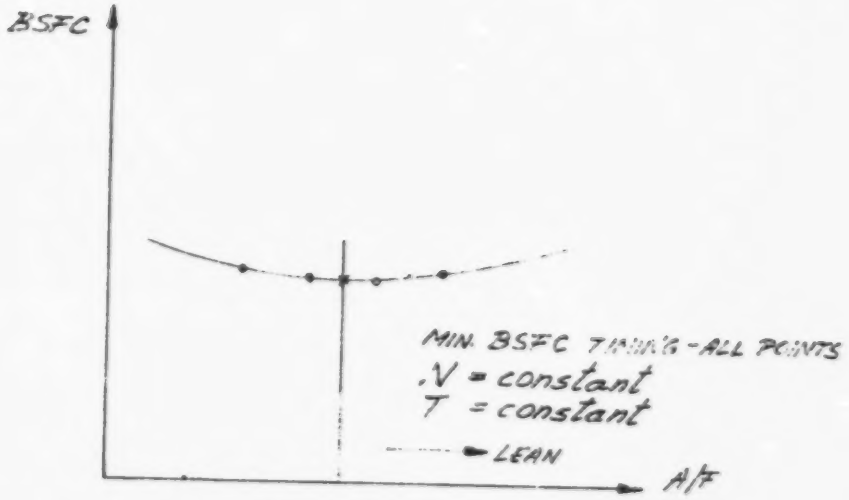


Figure 6-4: Principle of Air-Fuel Ratio Optimization at Partial Loads, for Minimum BSFC

- advance spark 3 degrees, run the test maintaining speed and torque constant and compute BSFC
- repeat until BSFC reaches a minimum and starts to rise again
- retard to the point of minimum BSFC and run the test to check that the value of BSFC is uncharged
- repeat in speed increments to maximum test speed

6.1.4 Influence of air-fuel ratio at partial loads (2/3 and 1/3 of maximum at WOT) - see Figure 6-4

- adjust carburetion system as per 6.1.2
- set ignition manually
- stabilize at lowest desired speed, 2/3 or 1/3 of the MBT torque, the carburetion system richer and spark retarded from the values necessary for minimum BSFC
- record timing and A/F ratio, run test and compute BSFC
- determine timing for minimum BSFC as per 6.1.3
- lean air-fuel mixture
- determine timing for minimum BSFC at new A/F ratio
- lean air-fuel mixture and readjust the timing for minimum BSFC until BSFC reaches a minimum and starts to rise again

- retard to the midpoint between the last two tests, check that the values are unchanged
- repeat in speed increments to maximum test speed

6.2 OPTIMIZATION RESULTS

6.2.1 Full load optimization

The results of MBT (minimum for best torque) timing determination at full load are summarized in Figure 6-5 and Table 6-1, for three different air-fuel ratio. The values of optimum timing increase for lean mixtures and are different from the commercial calibration, providing an improvement of 0.8 to 4.2% in specific fuel consumption at constant A/F. A mixture richer by 1.5 to 2.0 units yields a 1.0 to 2.1% increase in power, at the cost of 6.0 to 13.4% increase in specific fuel consumption. On the opposite side, a mixture leaner by 3.3 to 3.4 units will improve BSFC with 0.3 to 1.3% at a 13.3 to 14.2% reduction in power. In the same time, a richer or leaner mixture will reduce the average exhaust temperature with 24 to 145^{o}F. A mixture 0.75 to 1.0 units richer than stoichiometric is recommended, in order to have a power comparable with gasoline, together with acceptable specific fuel consumption and avoiding maximum exhaust temperatures. This compromise can be seen in Figure 6-6 and 6-7. The maximum power can be obtained at a 5.5 to 7.5% increase in BSFC from minimum obtainable. Otherwise, the best BSFC can be obtained, at a 6.7 to 10.7% reduction in power.

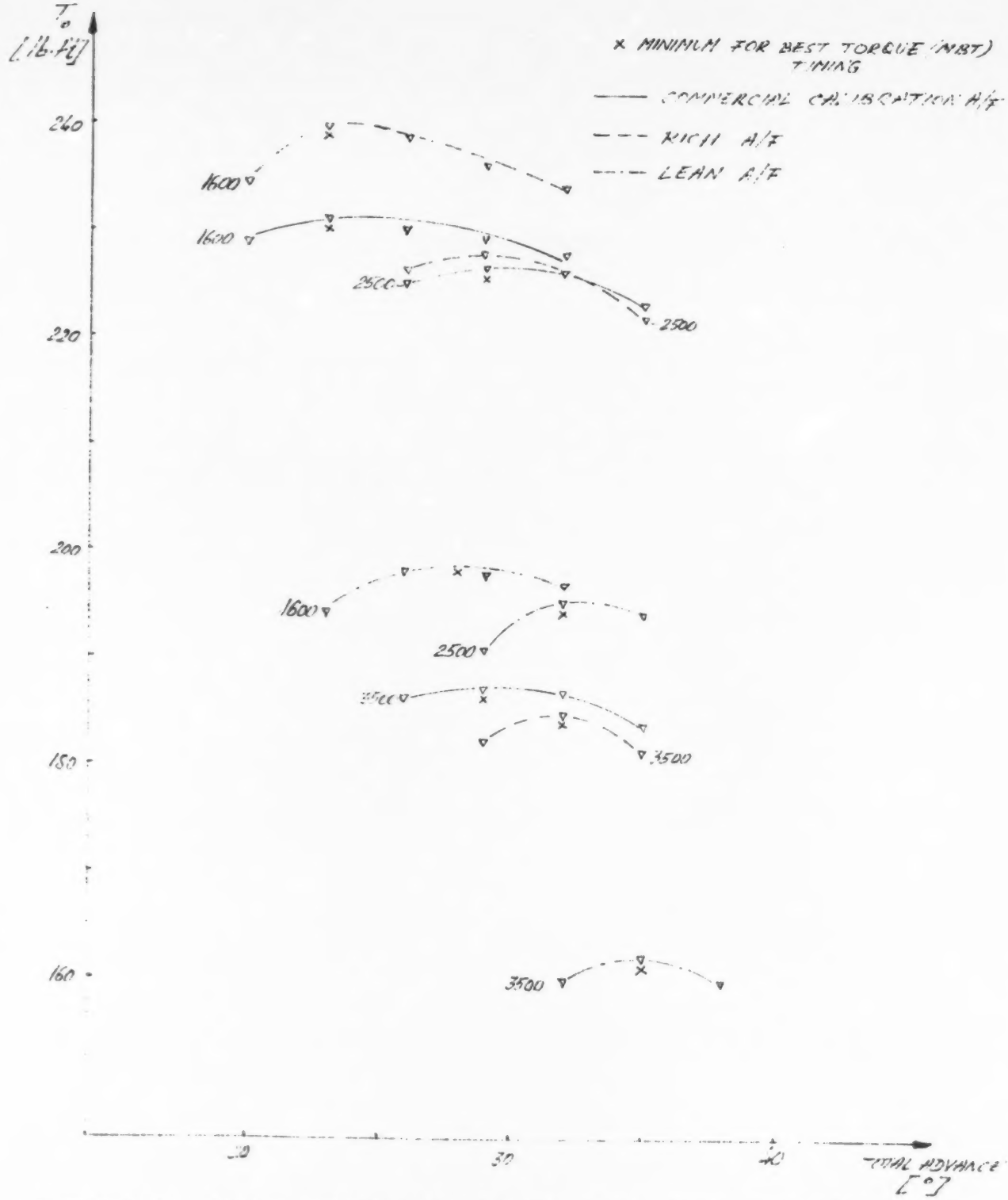


Figure 6-5: Timing optimization at full load, for MBT (minimum for best torque), on FORD 300 CID BF 251 engine

Table 6-1: Timing optimization at full load, for different air-fuel ratio

	UM	Commercial calibration			Rich			Lean		
Speed	rpm	1600	2500	3500	1600	2500	3500	1600	2500	3500
Observed torque	lb.ft	230.8	225.6	187.0	238.0	228.0	187.5	197.4	194.0	161.6
Corrected power % change	hp	69.74 -	106.04 -	123.61 -	71.21 +2.11	107.49 +1.37	124.83 +0.99	59.85 -14.18	91.45 -13.76	107.19 -13.28
OBSFC % change	lb/hp.h	.384 -0.78*	.388 -4.20*	.456 -1.94*	.407 +5.99	.437 +12.63	.517 +13.38	.381 -0.78	.387 -0.26	.450 -1.32
Optimum timing	0	23	29	29	23	29	32	28	32	35
A/F change vs. commercial	-	16.05 -	15.78 -	15.15 -	14.09 -1.96	14.06 -1.72	13.66 -1.49	19.35 +3.30	19.10 +3.32	18.61 +3.46
Fuel pressure	in H_2O	-1.90	-2.72	-3.20	+0.84	+1.53	+2.58	-2.60	-4.18	-6.00
Manifold vacuum	in Hg	1.01	1.99	3.15	0.98	1.99	2.94	0.95	1.84	3.06
Average exhaust temperature	^oF	1233	1328	1474	1198	1304	1362	1137	1213	1329

* re. 32^o constant timing, as in commercial calibration

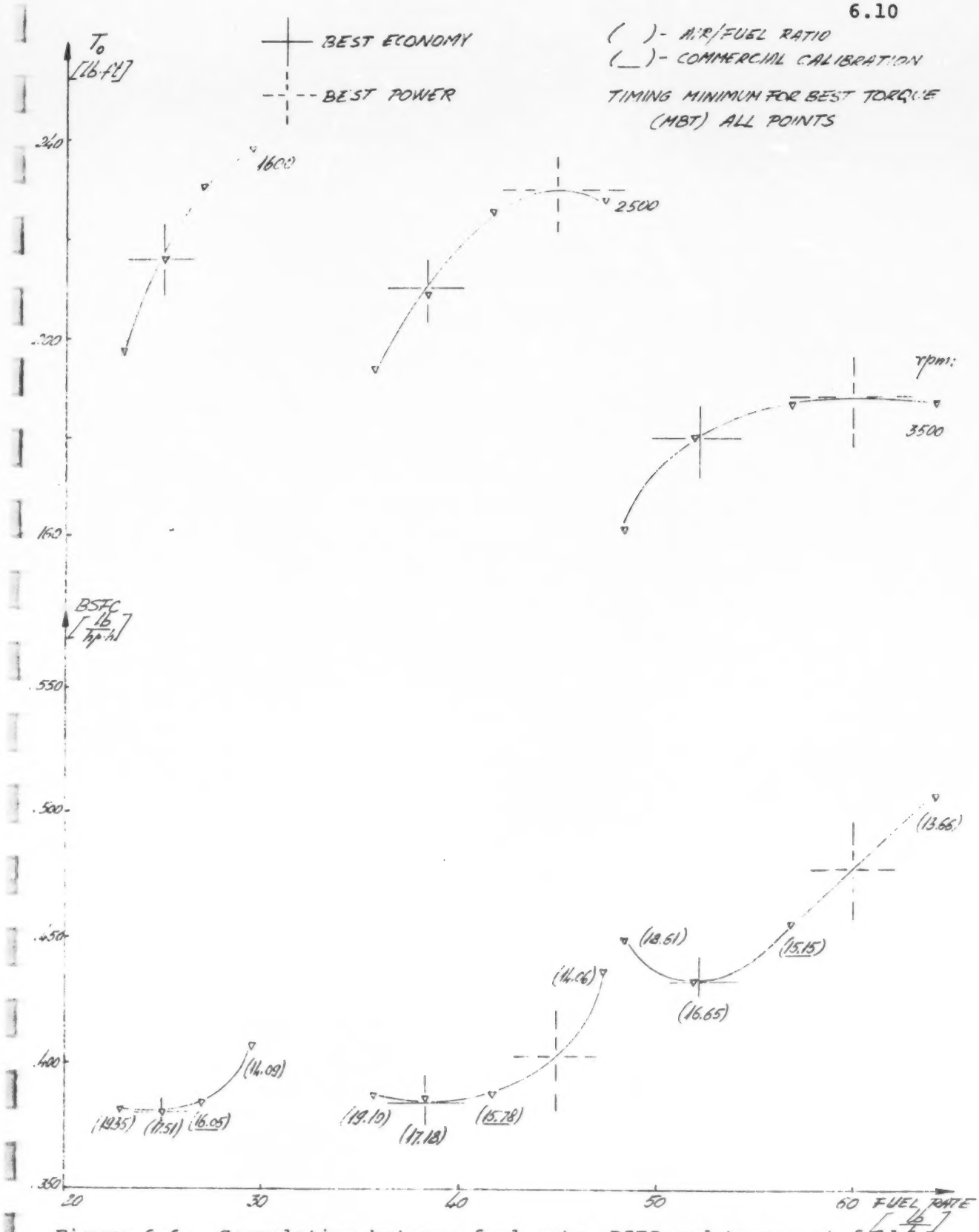


Figure 6-6: Correlation between fuel rate, BSFC and torque at full load for FORD 300 CED BF 251 engine

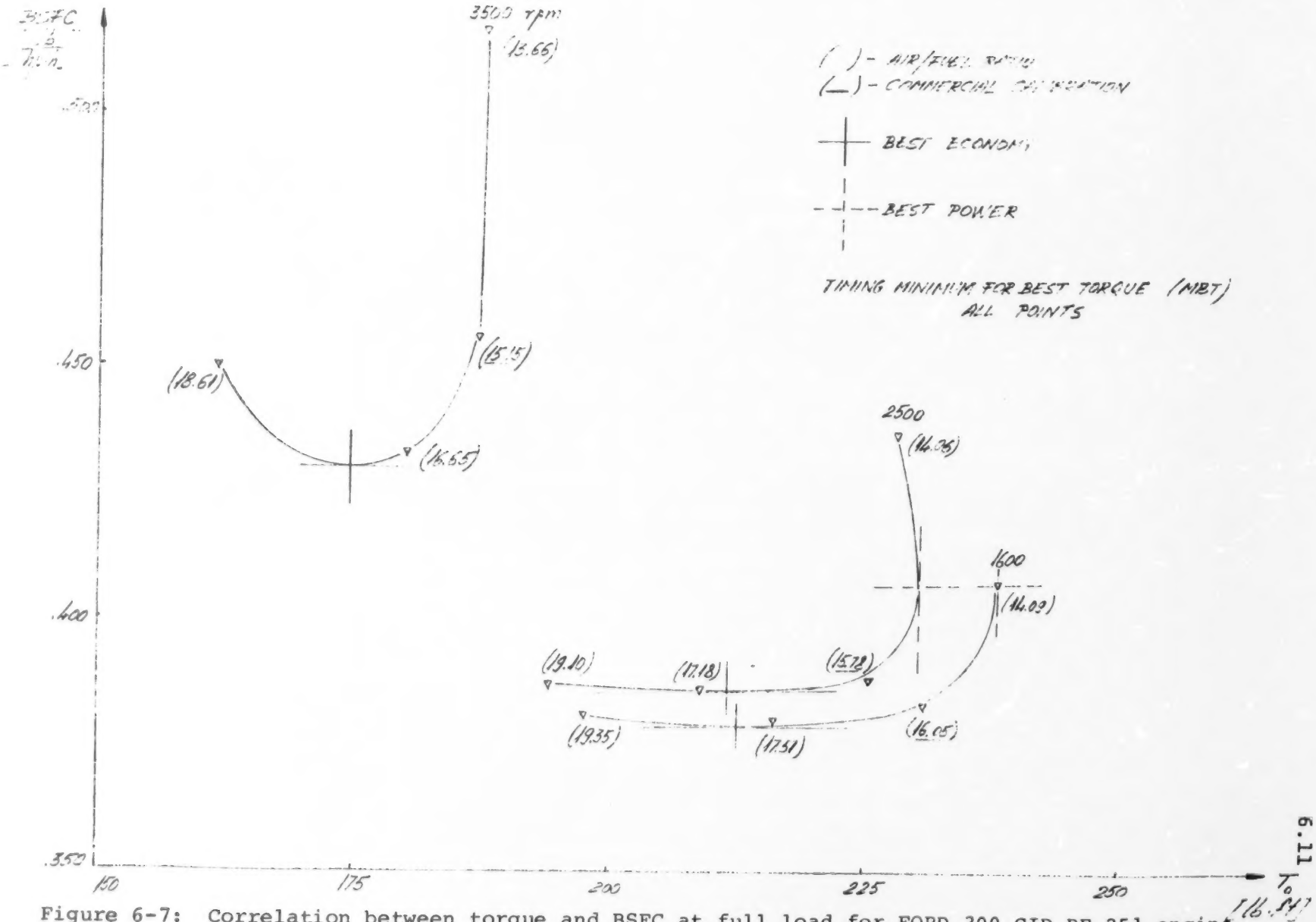


Figure 6-7: Correlation between torque and BSFC at full load for FORD 300 CID BF 251 engine

As power is the main concern at full load, a relative increase in specific fuel consumption has to be accepted.

6.2.2 Partial loads optimization

The search for optimum timing at partial loads is summarized in Figure 6-8. For the commercial A/F calibration of the IMPCO carburetion system on which the timing was tested, the 32^{o} total timing used coresponds to optimum conditions. For leaner mixtures, most favourable for BSFC and emission (especially NO), the optimum timing is higher. An overall picture of timing optimization of this engine is presented in Figure 6-9, in comparison with the standard practice used at the present time.

Each of the propane carburetion systems tested in this program was checked with the established optimum timing, at different air-fuel mixtures. The results are shown in Figures 6-10 to 6-12 and summarized in Table 6-2. The optimum A/F ratio has values between 19.3 and 22.4 (average 20.7), resulting in improvements of specific fuel consumption between 0.5 and 9.1%. Adding those improvements to the results of the commercial calibration of the propane carburetion systems vs. gasoline, the optimum results are presented in Table 6-3 and Figure 6-13. The

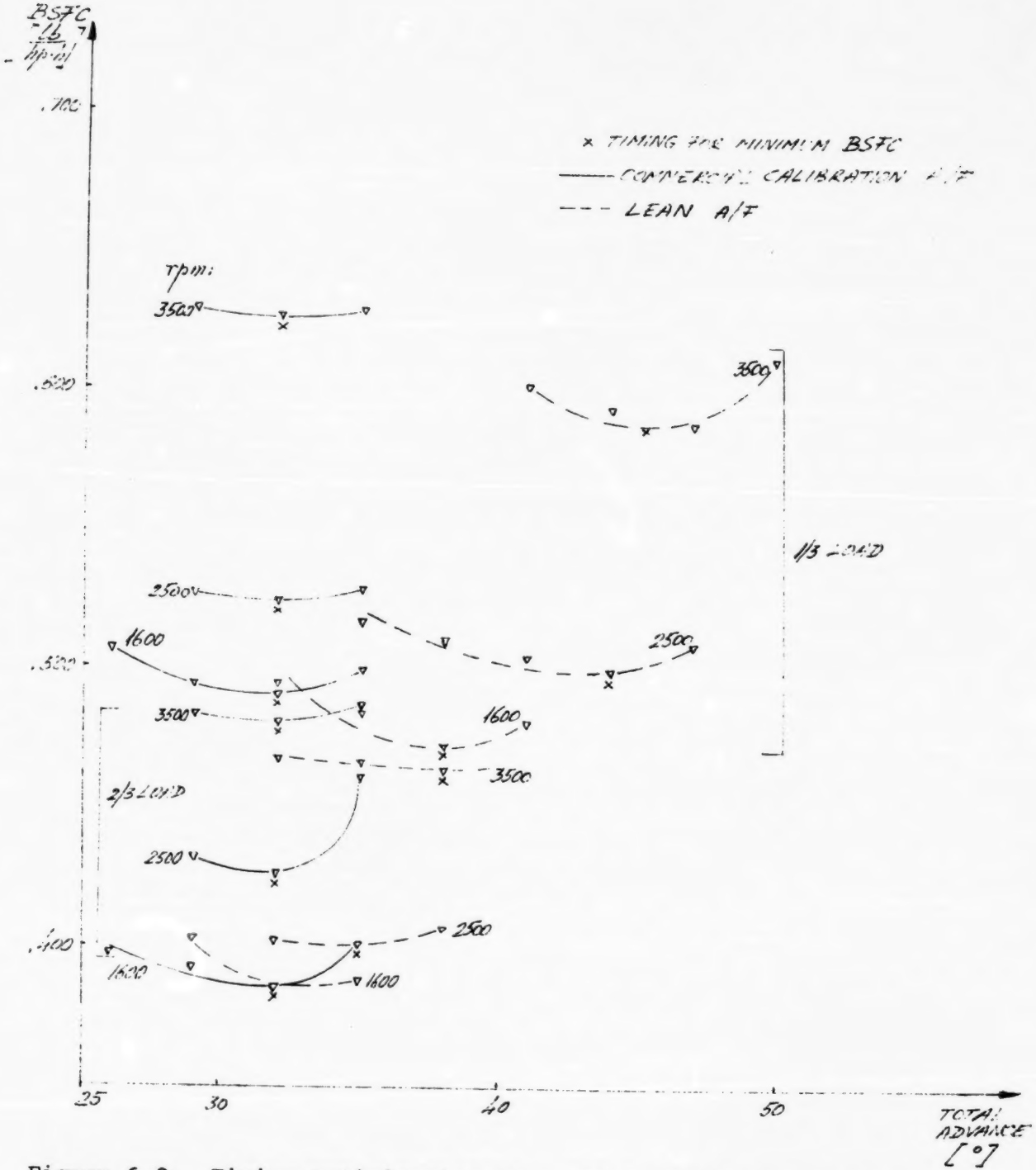


Figure 6-8: Timing optimization at partial loads, for best specific fuel consumption. (FORD 300 CID BF 251 engine)

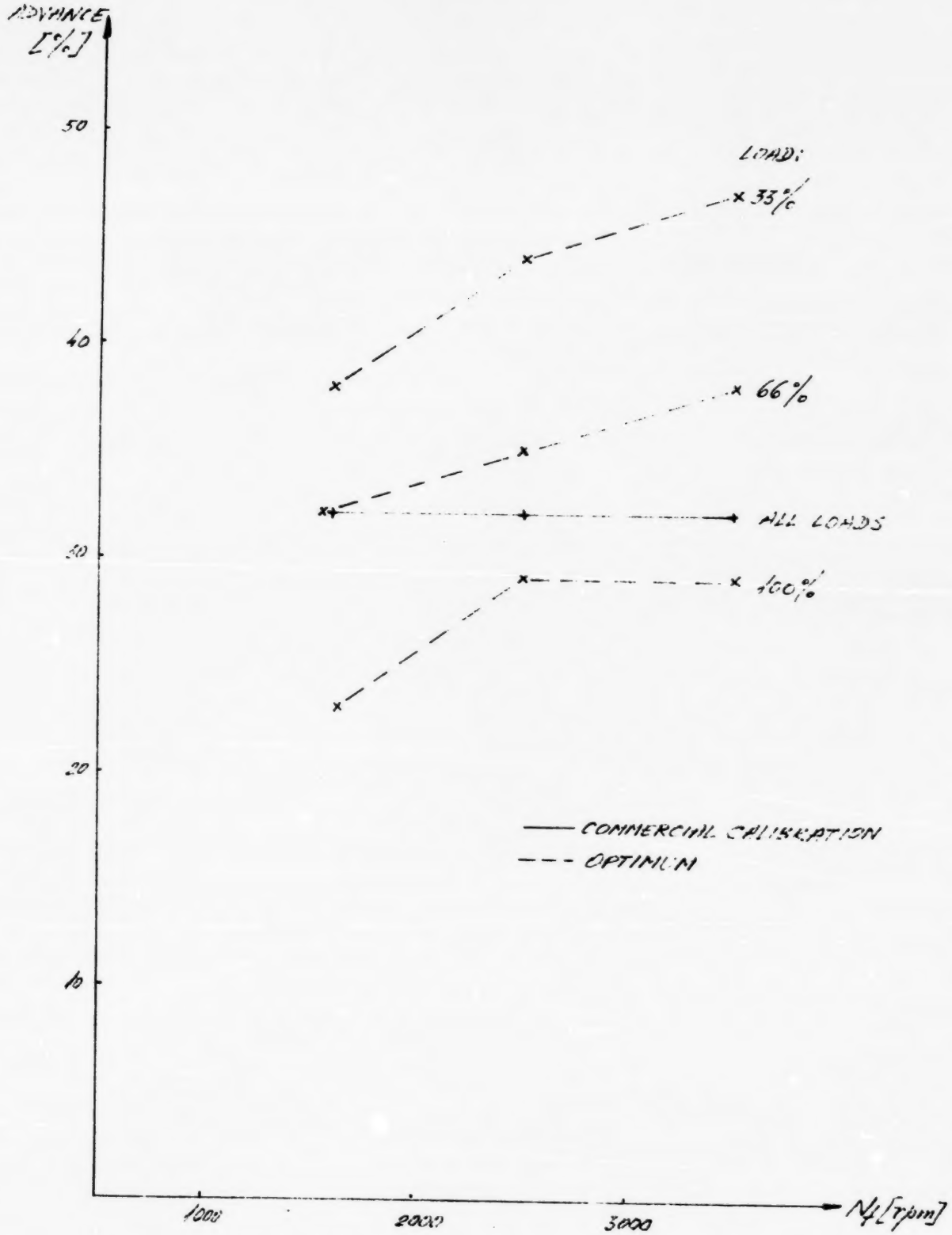
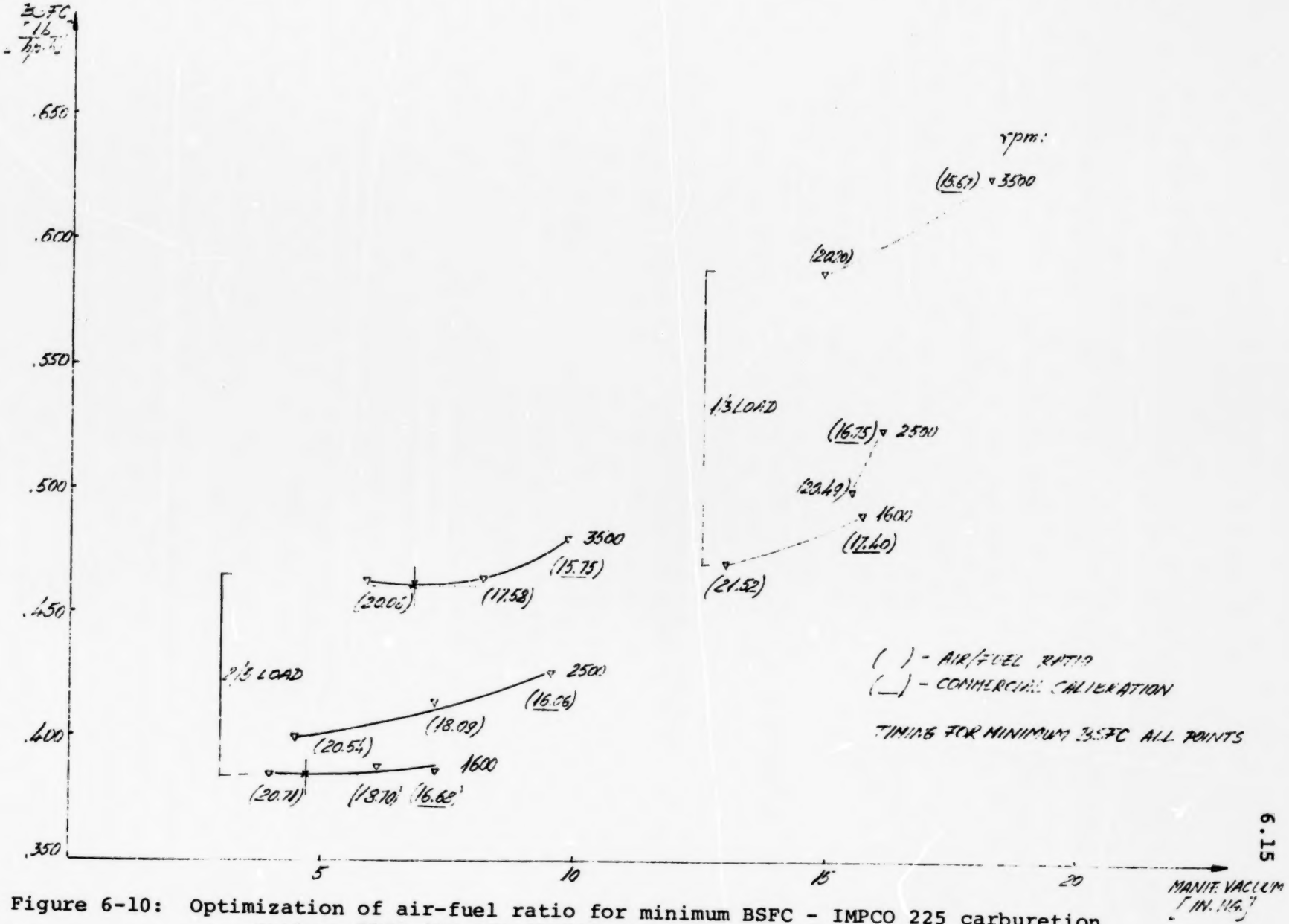


Figure 6-9: Optimum timing for FORD 300 CID BF 251 engine.



6.15

Figure 6-10: Optimization of air-fuel ratio for minimum BSFC - IMPCO 225 carburetion system, FORD 300 CID BF 251 engine

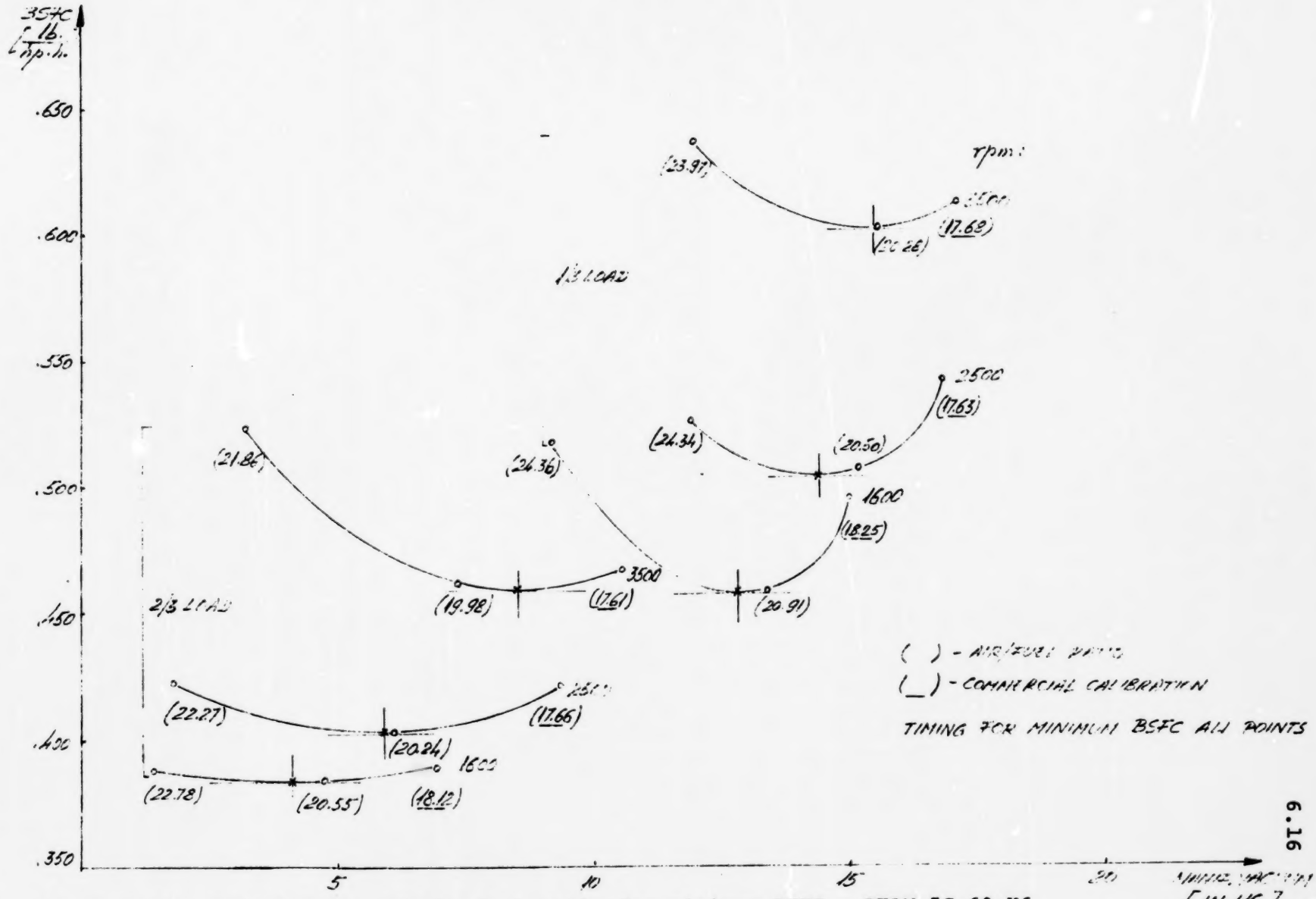


Figure 6-11: Optimization of air-fuel ratio for minimum BSFC - BEAM 5C-60-H6 carburetion system, FORD 300 CID BF 251 engine

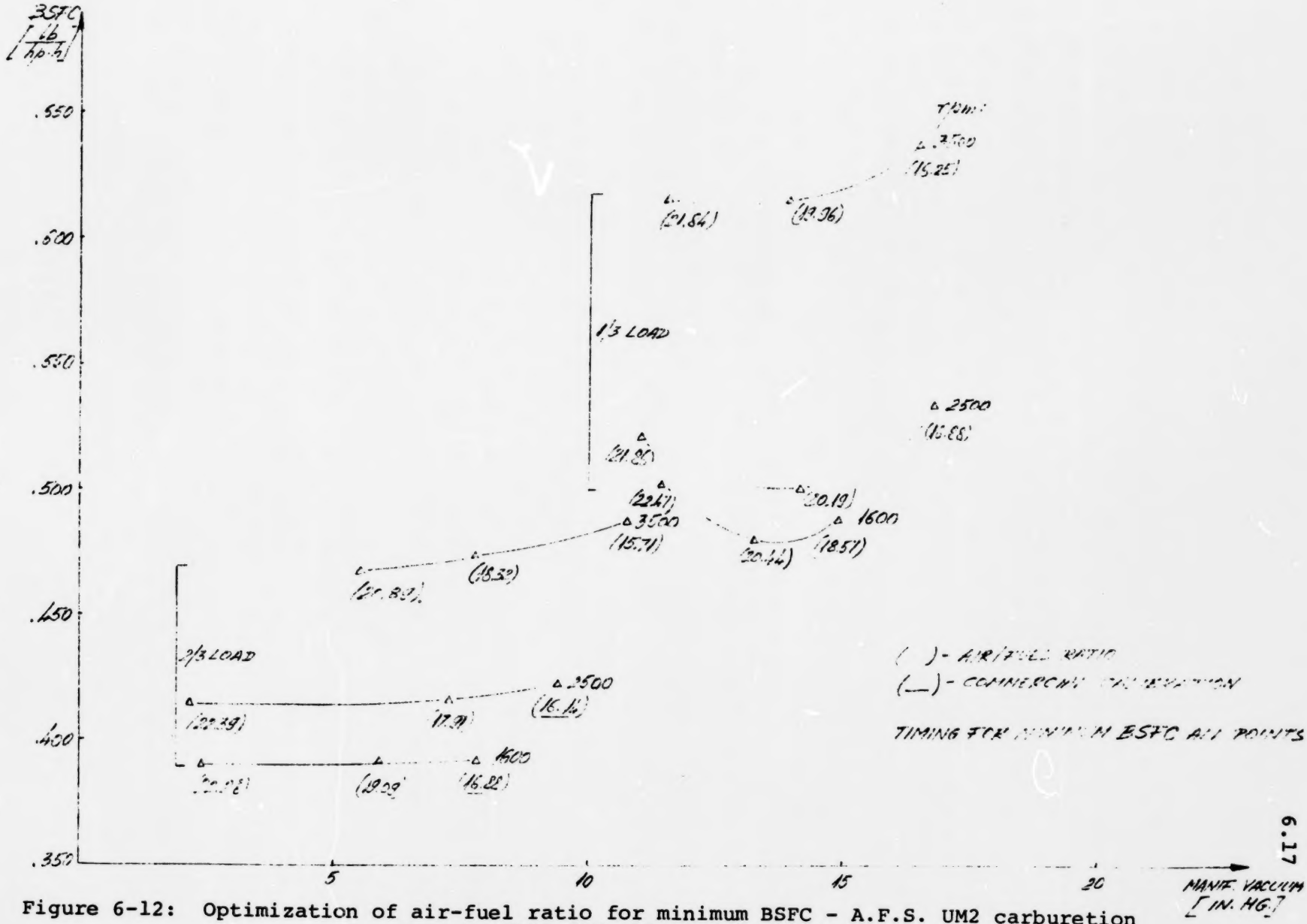


Figure 6-12: Optimization of air-fuel ratio for minimum BSFC - A.F.S. UM2 carburetion system, FORD 300 CID BF 251 engine

Table 6-2: Timing and A/F optimization at partial loads

	System	1600 rpm		2500 rpm		3500 rpm	
		66%	33%	66%	33%	66%	33%
Commercial calibration BSFC - Mass base lb/hp·h	IMPCO	.416	.500	.434	.541	.491	.646
	BEAM	.389	.495	.421	.542	.467	.613
	AFS	.392	.488	.423	.533	.487	.637
Optimum BSFC - Mass base lb/hp·h / % change	IMPCO	.385 / -7.45	.471 / -5.80	.400 / -7.83	.499 / -7.76	.460 / -6.31	.587 / -9.13
	BEAM	.383 / -1.54	.457 / -7.68	.403 / -4.28	.503 / -7.20	.460 / -1.50	.603 / -1.63
	A.F.S.	.390 / -0.51	.480 / -1.64	.415 / -1.89	.500 / -6.19	.468 / -3.90	.615 / -3.45
Optimum timing degrees / change vs. 32° commerc. calibr.	IMPCO	32 / 0	38 / +6	35 / +3	44 / +12	38 / +6	47 / +15
	BEAM	32 / 0	38 / +6	35 / +3	44 / +12	38 / +6	47 / +15
	A.F.S.	35 / +3	38 / +6	38 / +5	44 / +12	42 / +10	47 / +15
Optimum A/F value / change vs. commerc. calibr.	IMPCO	20.7 / +4.0	21.5 / +4.5	20.5 / +4.4	20.5 / +3.7	19.5 / +3.7	20.2 / +4.5
	BEAM	20.8 / +2.7	21.3 / +3.0	20.3 / +2.6	20.7 / +3.1	19.3 / +1.6	20.3 / +2.6
	A.F.S.	22.3 / +5.4	20.4 / +1.8	22.4 / +6.3	20.2 / +3.3	20.9 / +5.2	20.0 / +3.7

energy efficiency at partial loads, the most common operating conditon for vehicles, is increased by an average of 3.9% at 2/3 load and 5.6% at 1/3 load. As can be seen in Figure 6-13, the advantage of propane at partial loads is improved, contributing to a more uniform efficiency increase between no load and full load.

Table 6-3: Improvements in energy efficiency [%] after timing and A/F optimization

Load [%]	Average for 3 systems	Engine speed [rpm]			Average
		1600	2500	3500	
66	before optim.	+8.25	+7.44	+5.87	+7.19
	improvement	+3.17	+4.67	+3.90	+3.91
	total after optim.	+11.42	+12.11	+9.77	+11.10
33	before optim.	+3.45	+1.47	+2.76	+2.56
	improvement	+5.04	+7.05	+4.74	+5.61
	total after optim.	+8.49	+8.52	+7.50	+8.17

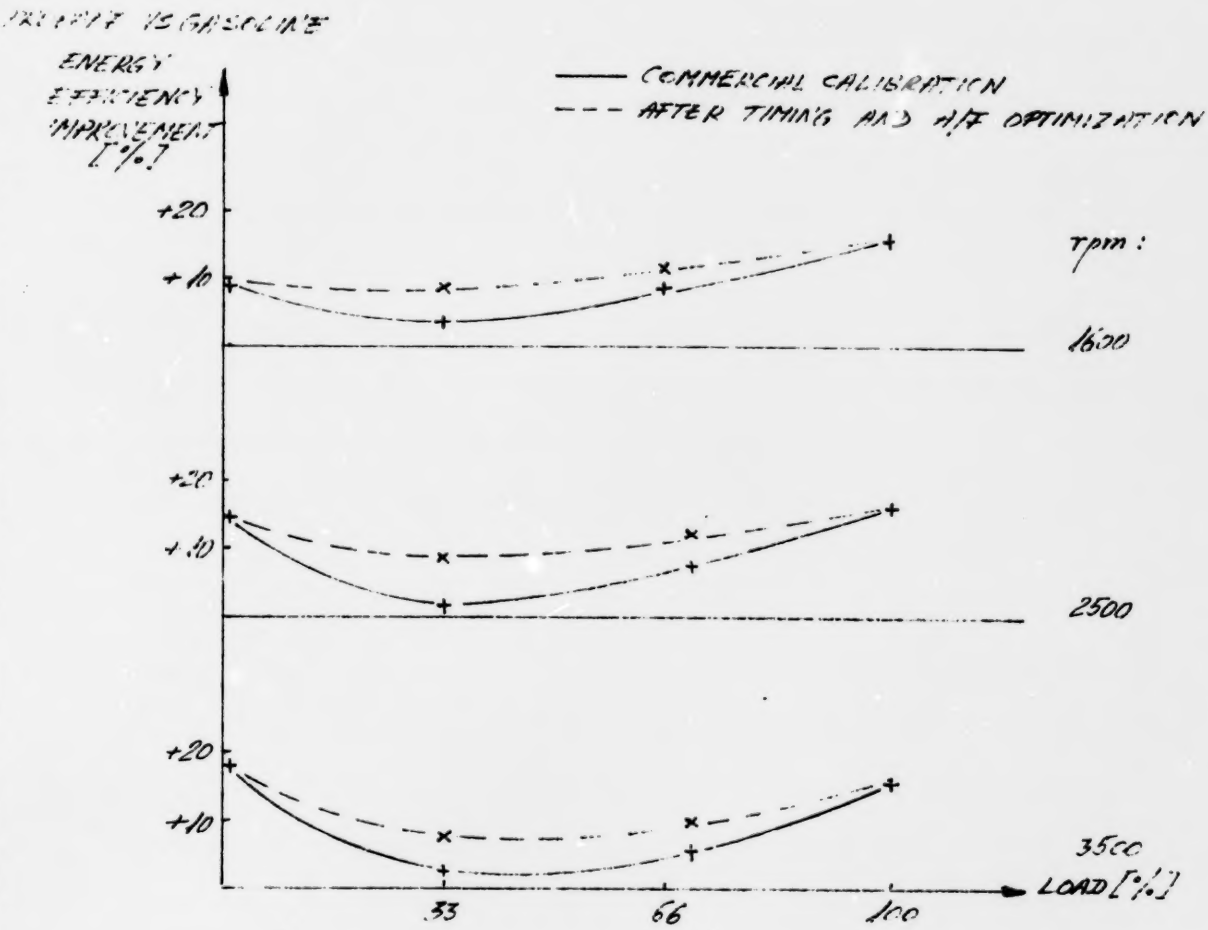


Figure 6-13: Average improvement of energy efficiency of propane carburetion systems vs. gasoline, after timing and air-fuel ratio optimization

7. DYNAMIC PRESSURE EVALUATION

For a better understanding of the internal processes in the propane carburetion systems and their correlation with the economy of the system, a series of dynamic pressure measurements was carried out. The results are presented in this chapter.

The carburetion systems tested until now for the two engines, have a negative pressure in the fuel supply line between regulator and mixer (carburettor). The only exception is the ALGAS system, which has a one stage regulator and a positive supply pressure of about 5 psi, the proportion of fuel mixed with air being controlled by a valve in the carburettor. The negative pressure in the fuel line has the advantage of eliminating leakages. The resulting potential improvement in accuracy and stability of pressure control is claimed by many makers as a special feature of their equipment. Certain manufacturers claim that this leads to a potential improvement in economy.

A vacuum signal proportional to the quantity of air passing through the carburettor is applied to the last (second or third) stage of the regulator, controlling the opening of the corresponding valve and consequently the quantity of fuel withdrawn. The correlation between the signal applied and the actual quantity of fuel supplied can

be established by modifying the restrictions in the line, to obtain the desired air-fuel ratio.

The fuel supply pressure between the regulator and carburettor was recorded under different dynamic situations, together with a number of related events to help locate in time the cause-effect phenomena in the system:

- inlet manifold vacuum
- reference pressure for second stage of regulator (for IMPCO system)
- engine speed and torque

The air-fuel ratio was controlled by variation of the reference pressure in the regulator's second stage for the IMPCO system and by the position of the "power" valve in the fuel line for BEAM and A.F.S. systems.

In Figure 7-1, the record of a start and after-speed and torque increases for IMPCO carburetion system is reproduced. The fuel pressure decreased from zero at rest to -5.32 in. H_2O and stabilized after at -1.4 in H_2O for a speed of 1600 rpm. A further increase in speed and the application of a load to the engine resulted in some disturbances to the fuel pressure as well as the appearance of a ripple of about 0.35 in. H_2O in the fuel pressure.

To obtain a leaner mixture for the IMPCO carburettor, a vacuum of -2.4 in. H_2O was applied on the reference side of the regulator second stage (Figure 7-2). The record was stopped and resumed with the torque and speed of the engine kept constant through variation of the throttle position

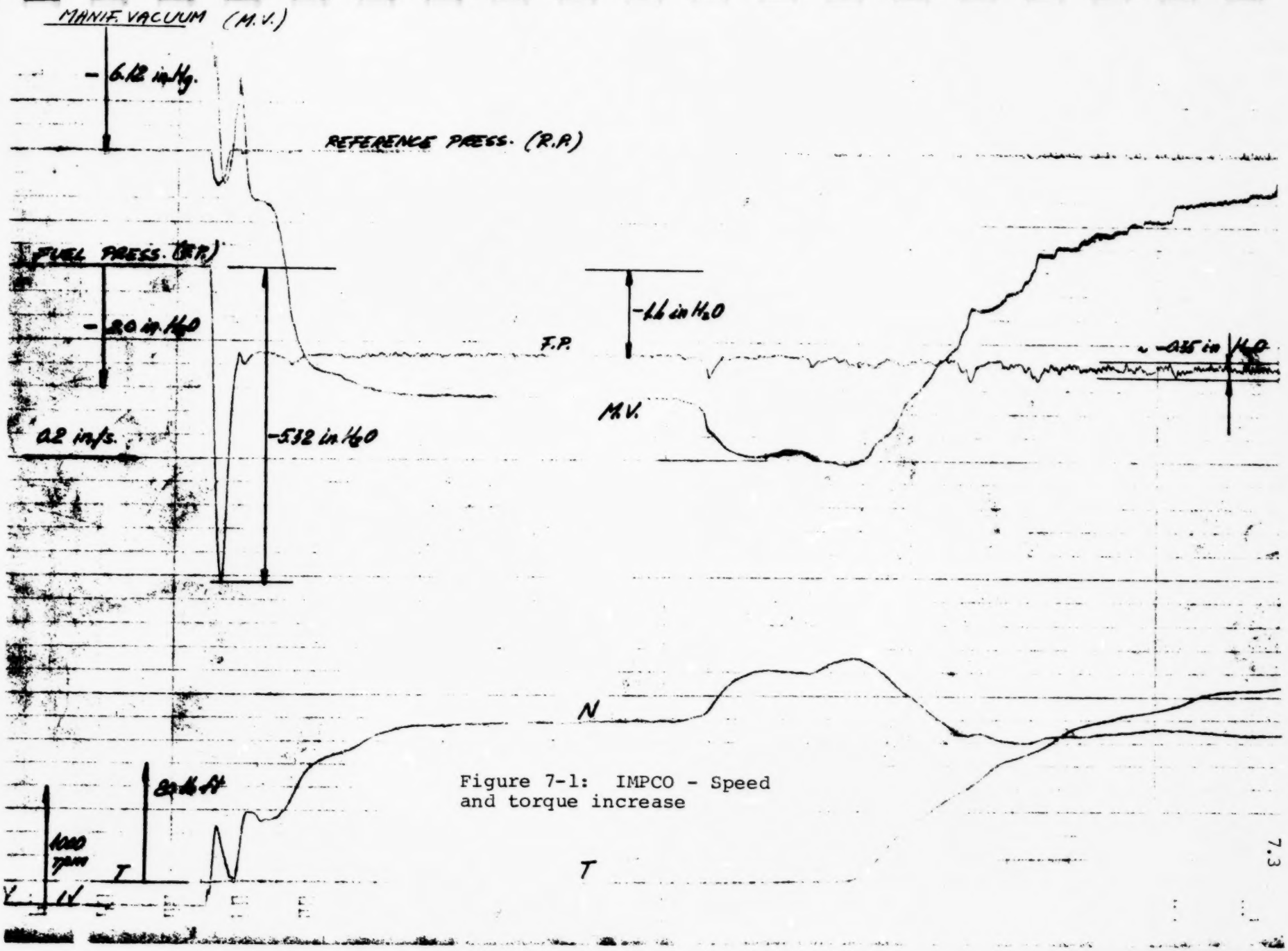


Figure 7-1: IMPCO - Speed and torque increase

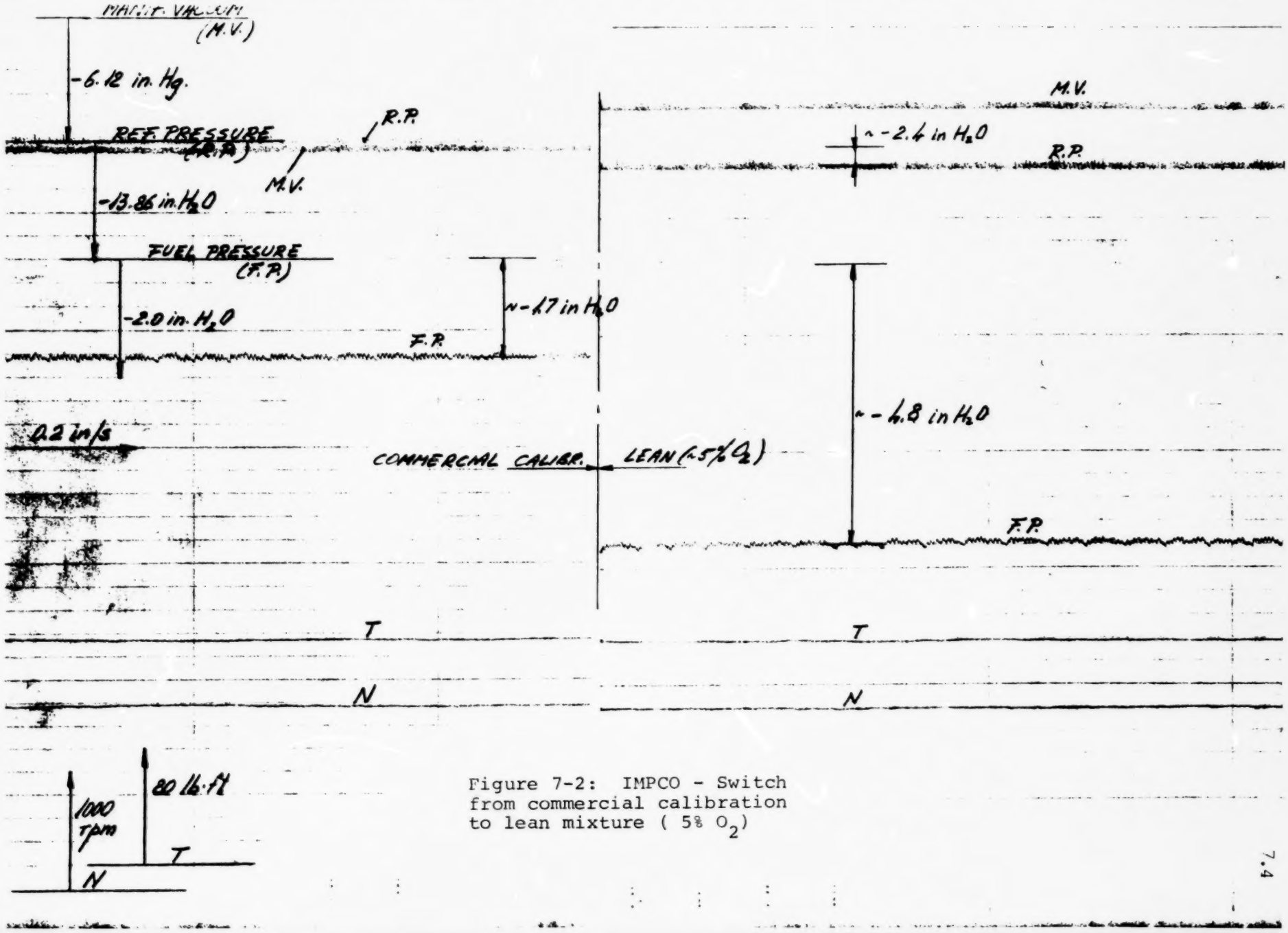


Figure 7-2: IMPCO - Switch from commercial calibration to lean mixture (5% O_2)

(see drop in manifold vacuum after the throttle opening to keep N and T constant at leaner mixture). The fuel pressure dropped to -.48 in. H_2O and was fairly linear, with a small ripple present.

The switching back to normal reference pressure is recorded in Figure 7-3, with the same fairly stable response.

Application of a heavy load at 3200 rpm and WOT is presented in Figure 7-4.1. The fuel pressure drops from -1.35 to -2.7 in. H_2O (average), accompanied by frequent (10-13 Hz) fluctuations of about 0.6 - 0.7 in. H_2O describing the opening-closing cycles of the valves in the system. This vibration is damped in approximately 85s to 0.2 - 0.3 in. H_2O (Figure 7-4.2). Details of the vibration signal can be observed at a record speed ten times higher.

The relatively slow response of this carburetion system is illustrated in Figure 7-5, for a reduction of load between maximum and zero. The fuel pressure increases from -2.3 to +3.35 in. H_2O, determined by the closure of the air valve in the carburettor and varies erratically for about 8s before stabilizing at -0.3 in. H_2O.

The BEAM carburetion system analysis begins in Figure 7-6 with an engine start and some speed *drills*. The starting process of the engine took about 1.7s at 200 rpm and the fuel pressure stabilized at -0.35 in. H_2O. A variation of speed from 1500 to 3000 rpm twice determined two sharp decreases in pressure to -2.25 in. H_2O without

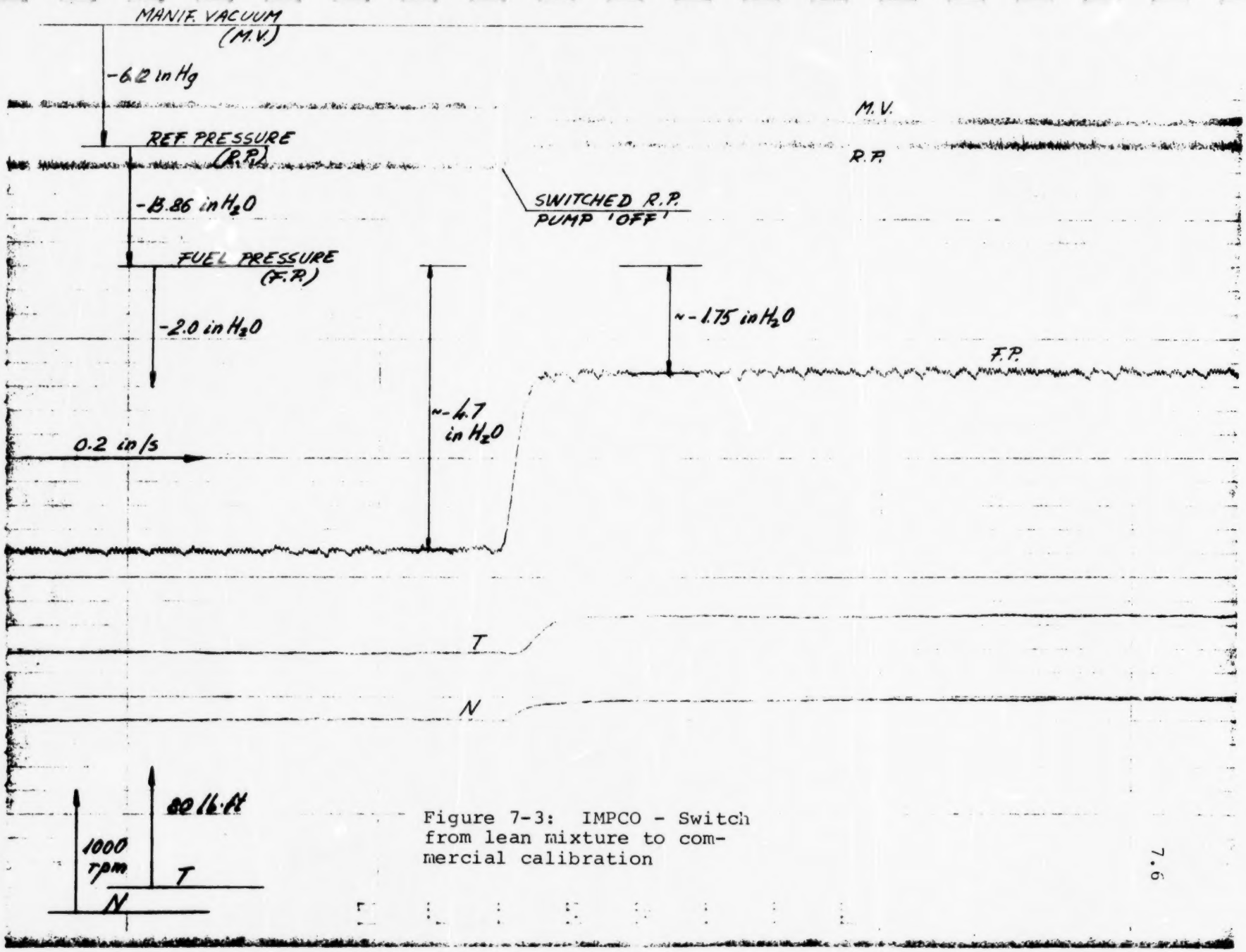


Figure 7-3: IMPCO - Switch from lean mixture to commercial calibration

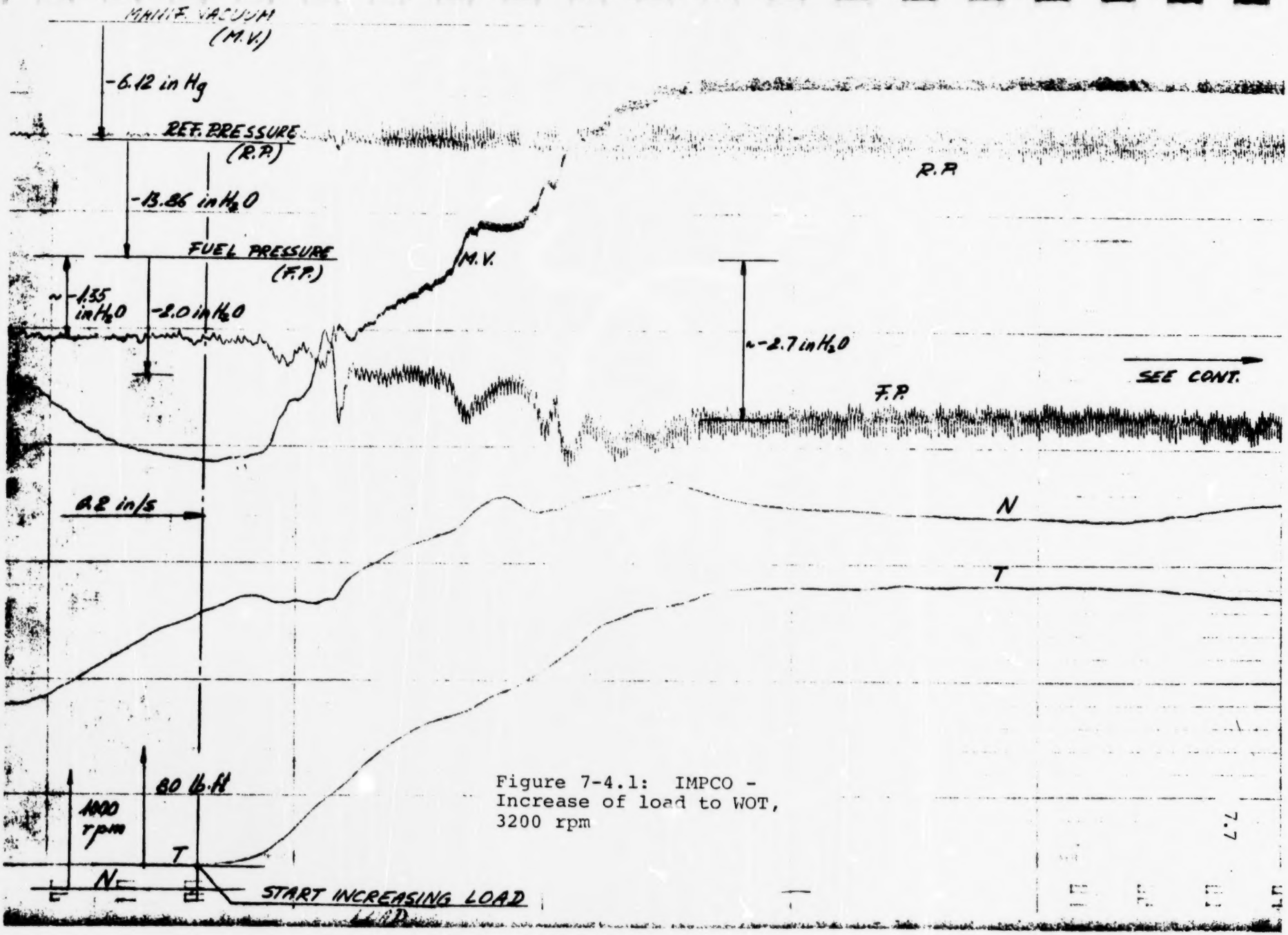


Figure 7-4.1: IMPCO - Increase of load to WOT, 3200 rpm

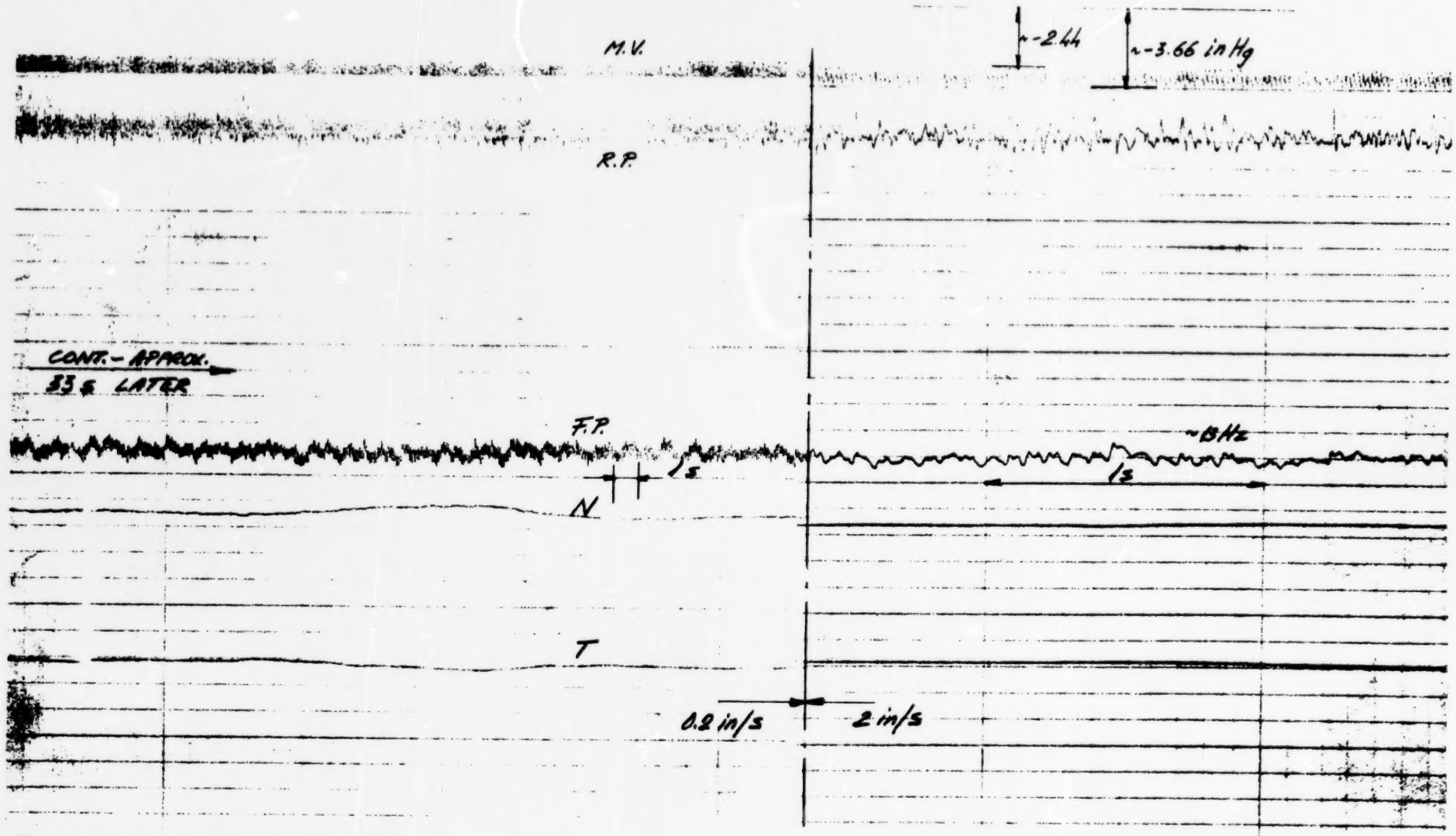


Figure 7-4.2: IMPCO - Increase of load to WOT, 3200 rpm

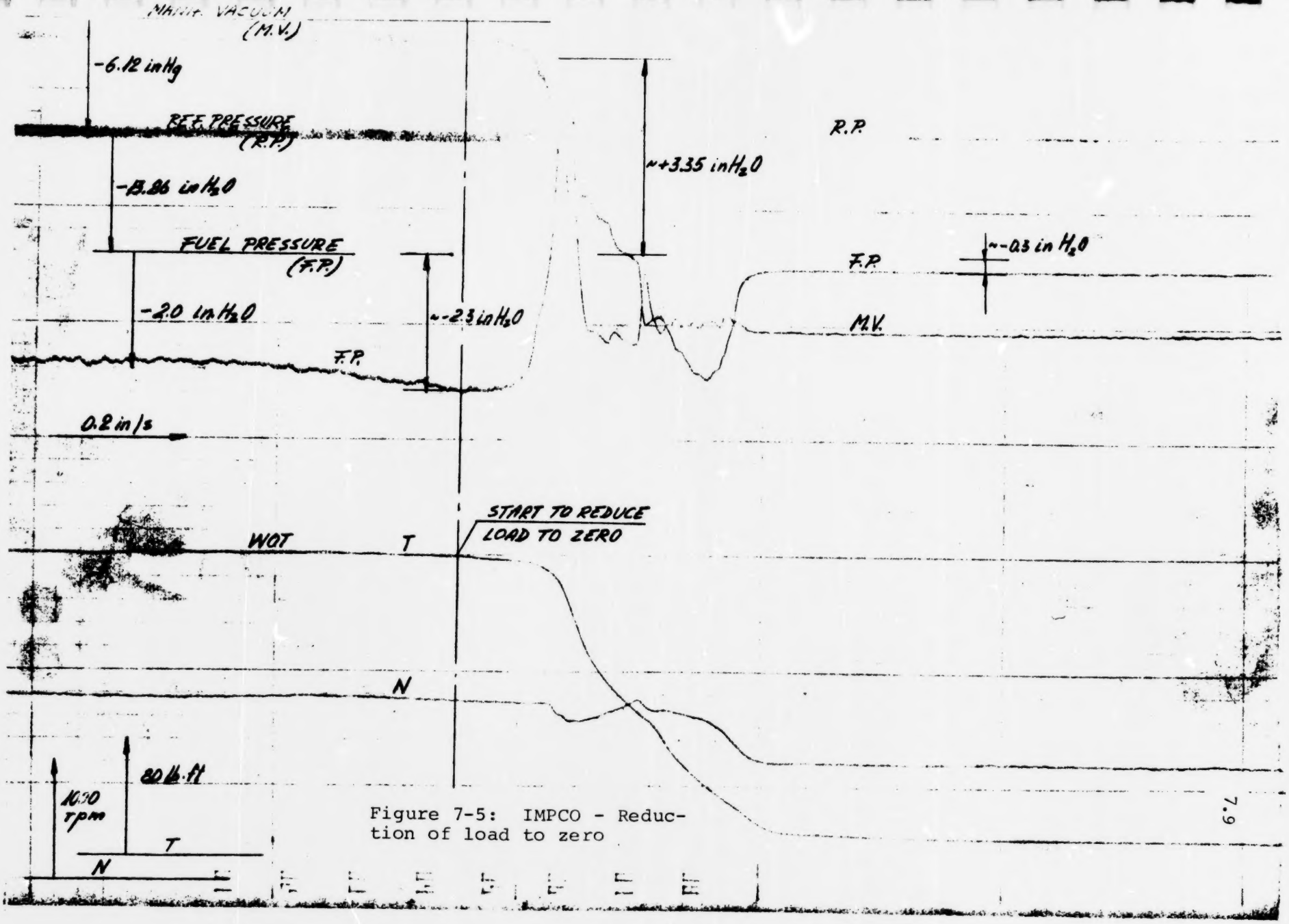


Figure 7-5: IMPCO - Reduction of load to zero

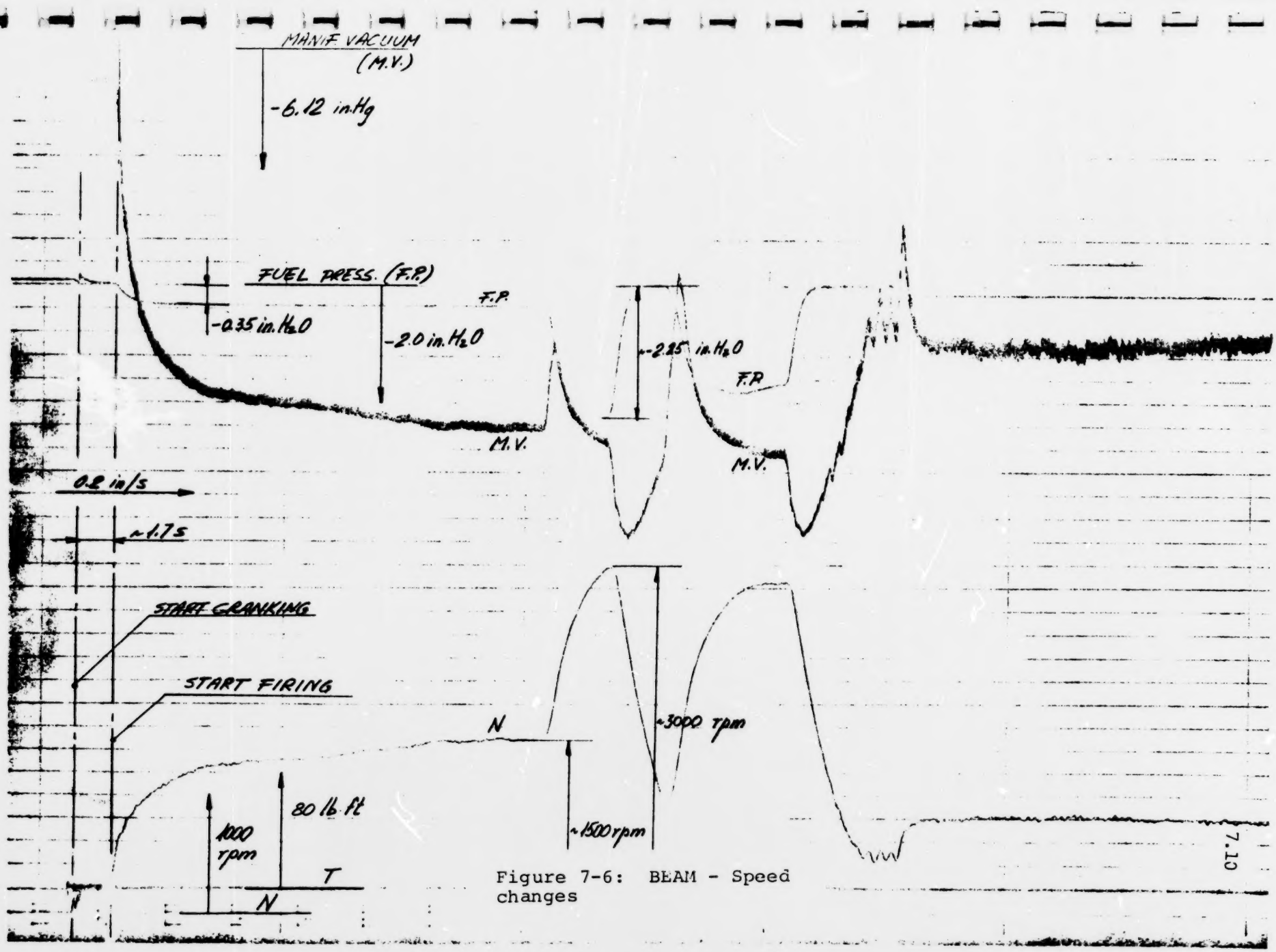


Figure 7-6: BEAM - Speed changes

sharp overshooting, but with an over-return to zero pressure upon speed reduction. The fuel pressure returned immediately after the end of the speed variation to a value of -0.15 in. H_2O. The loading of the engine up to 155 lb.ft at 1600 rpm resulted in a smooth reduction of fuel pressure to -1.7 in. H_2O (Figure 7-7). In Figure 7-8.1 and 7-8.2, a similar rpm and torque increase is recorded with a speed chart 40 times higher to magnify any possible ripple in the fuel pressure. The record remained very smooth, with a minimum pressure of -3.75 in. H_2O, and stabilized after approximately 1.75 s at -1.95 in. H_2O. The manifold vacuum ripple is clearly presented in this record, the frequency increasing with the speed. A reduction of the load and rpm recorded with the same high chart speed in Figure 7-9, presents a similar stable and fast response of the fuel pressure. This pressure varied from -4.1 to -0.4 in. H_2O. The absence of moving parts in this carburettor (e.g.: the air valve in IMPCO system) was responsible for the favourable fuel pressure control.

The response of the A.F.S. system is presented beginning with Figure 7-10, for rpm variation without load. After transients between -0.12 and -0.28 in. H_2O for about 1 s, the fuel pressure returned in a very stable manner to a value of -0.11 in. H_2O. The same very stable behaviour can be observed in Figure 7-11 for an increase and decrease of load up to WOT. The pressure varied only between -0.20, -0.35 and -0.24 in. H_2O during the transients and had a very

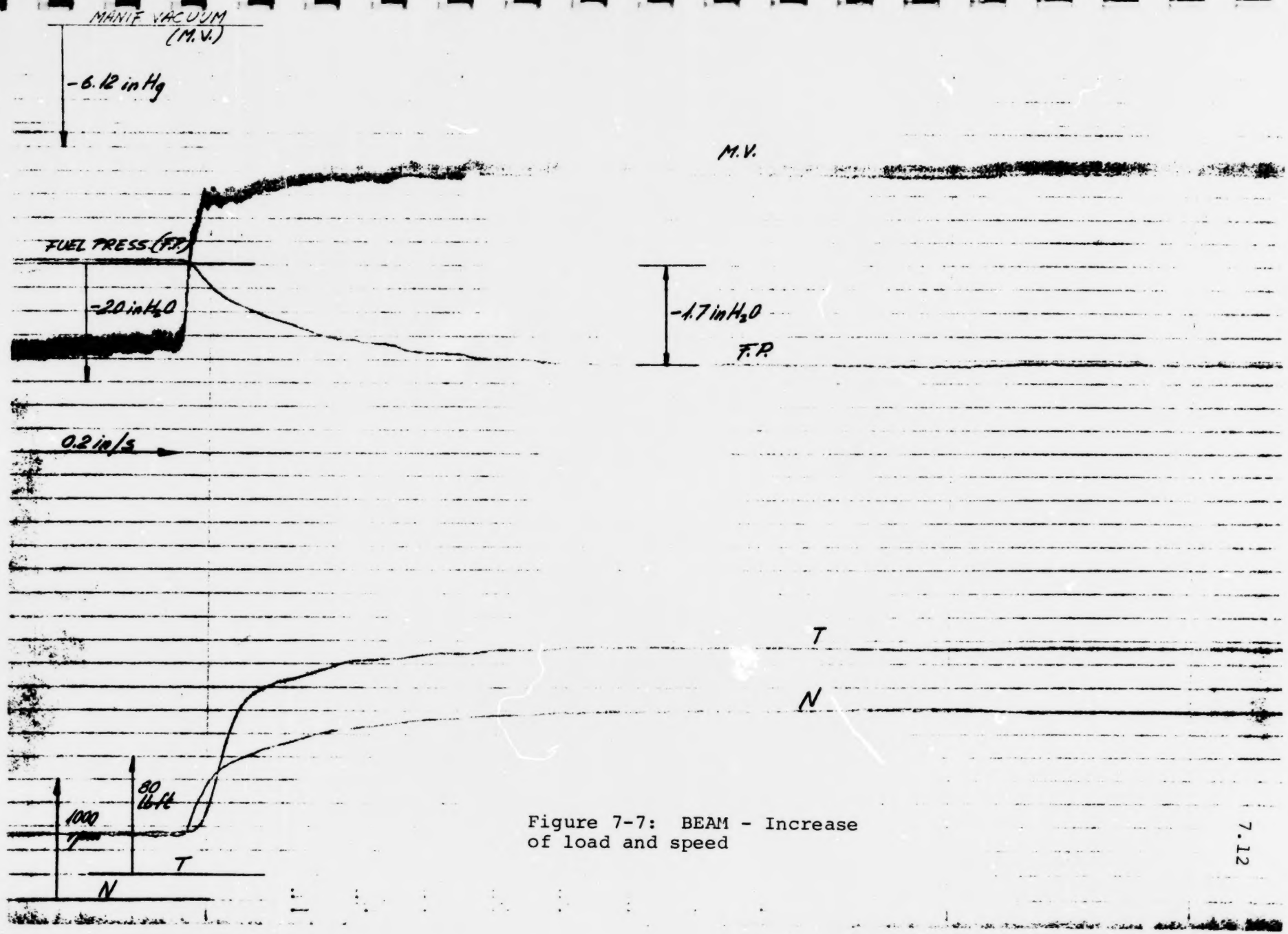


Figure 7-7: BEAM - Increase of load and speed

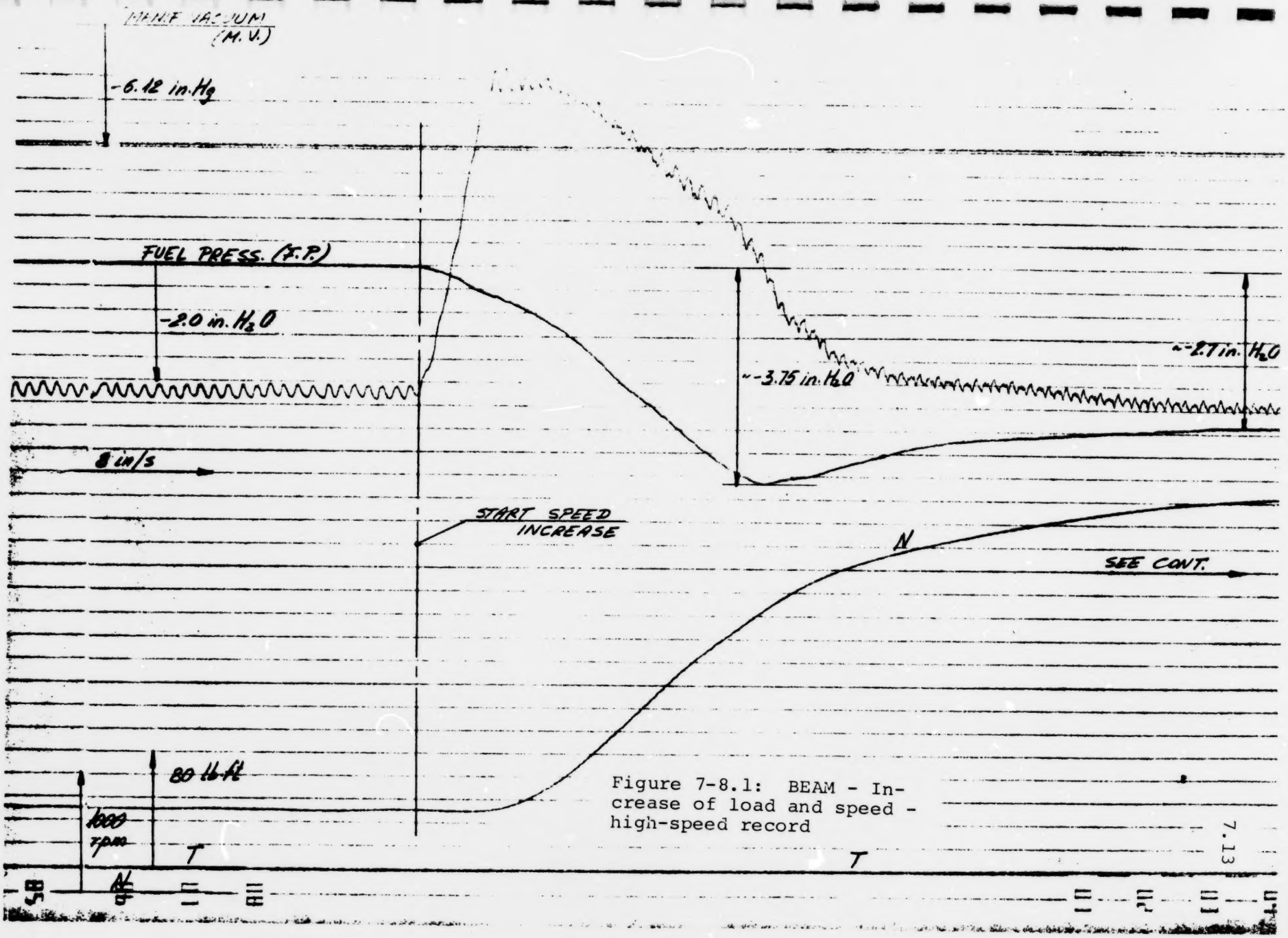


Figure 7-8.1: BEAM - Increase of load and speed - high-speed record

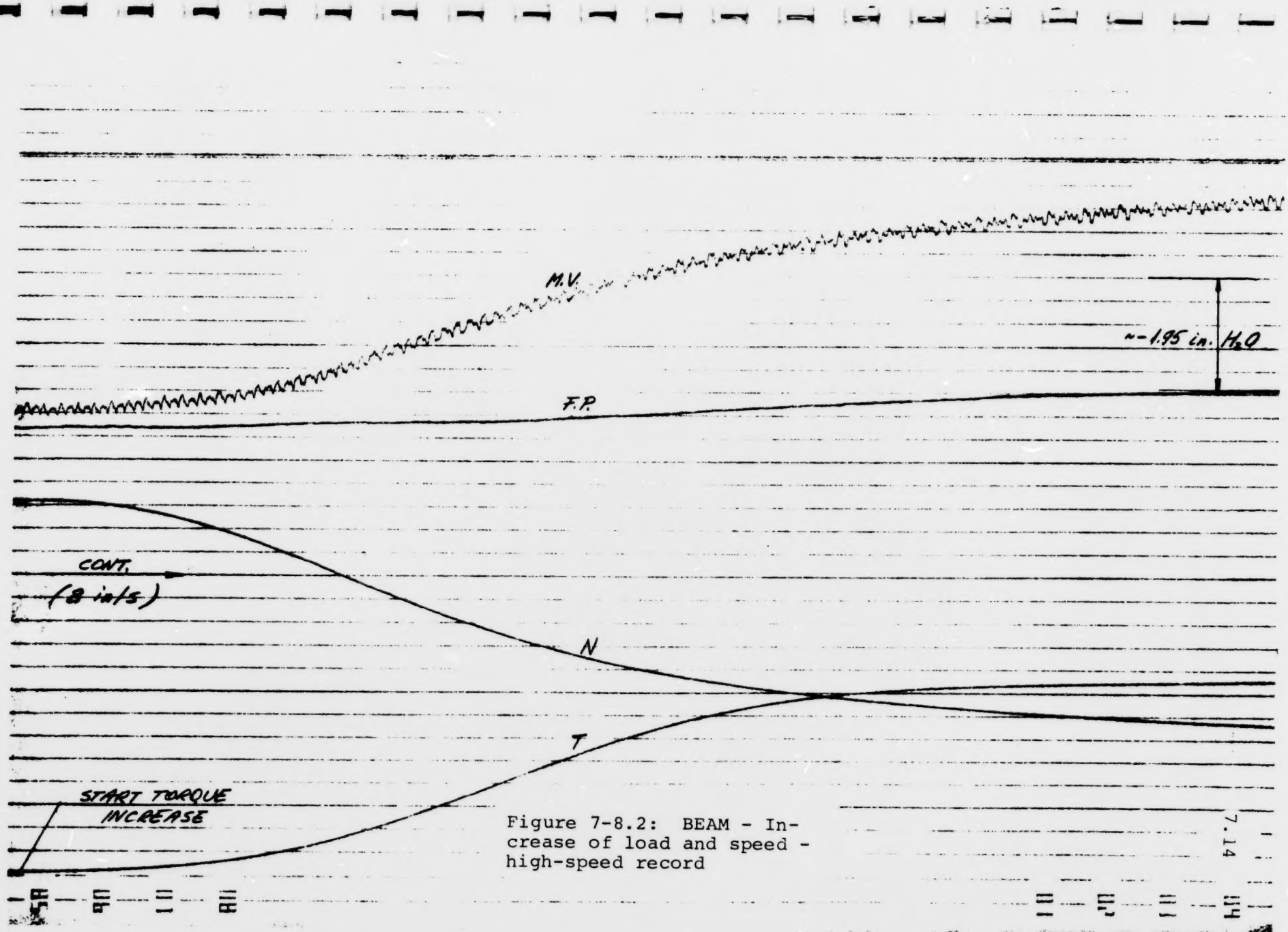


Figure 7-8.2: BEAM - Increase of load and speed - high-speed record

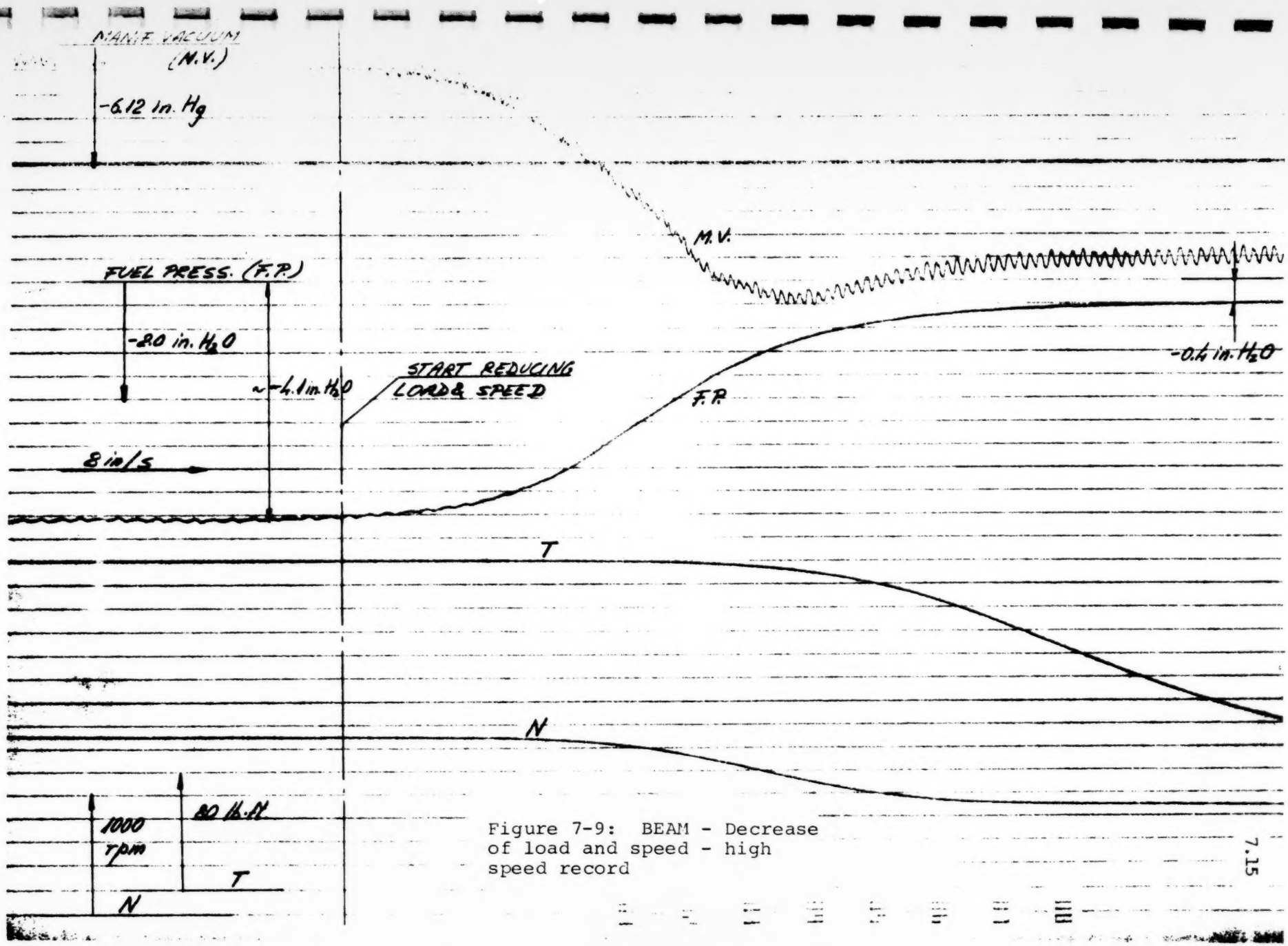


Figure 7-9: BEAM - Decrease of load and speed - high speed record

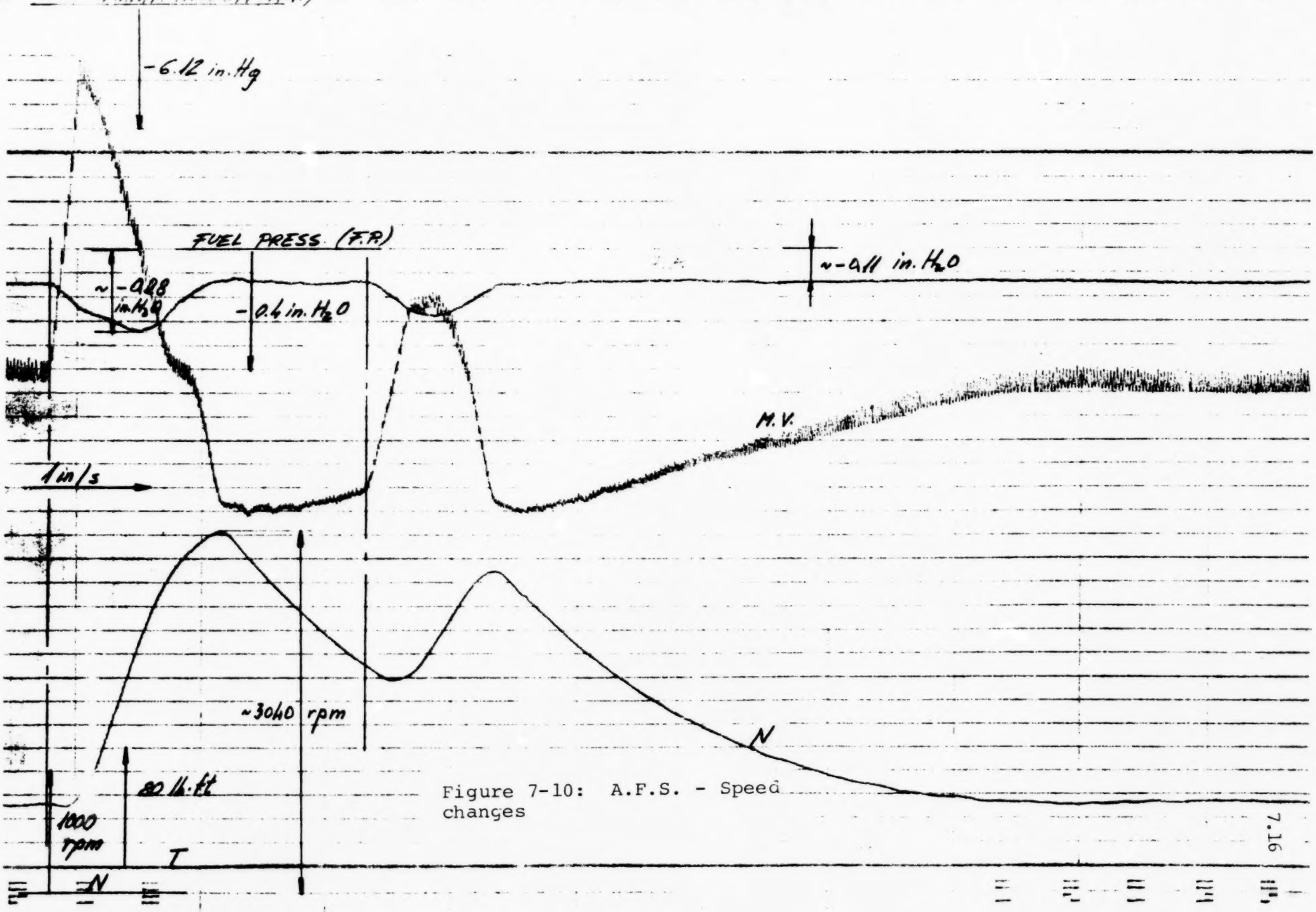


Figure 7-10: A.F.S. - Speed changes

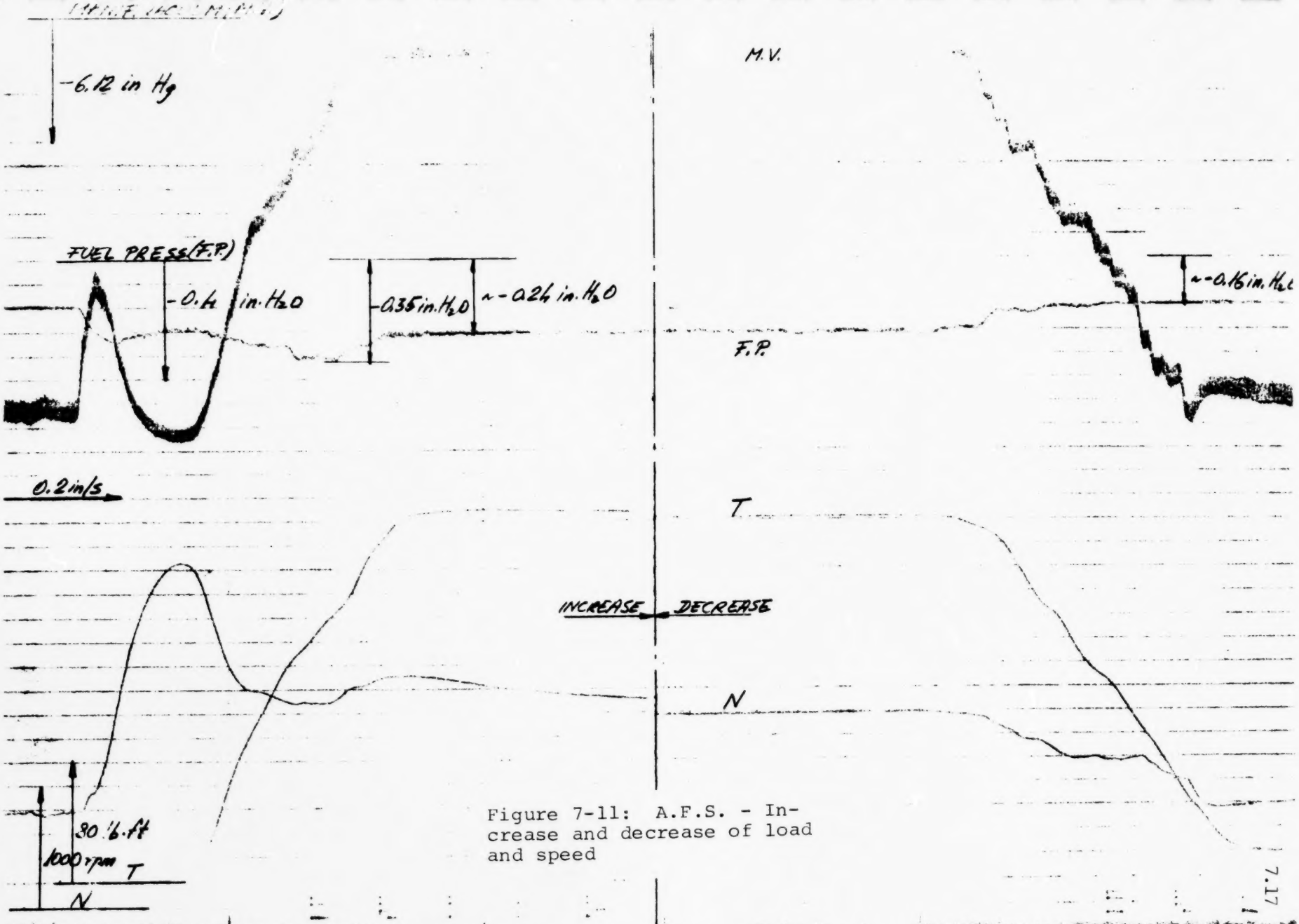


Figure 7-11: A.F.S. - Increase and decrease of load and speed

low ripple under constant load. Similar observations are noted in Figure 7-12, where the increase of load determined the reduction of speed from 2850 to 1800 rpm.

The above results show the response of the A.F.S. system to be only slightly less stable than for the BEAM system and the values of fuel pressure are closer to atmospheric. That is to be expected for a regulator with 3 stages, where the sensitivity of the last stage is higher. The picture changes in Figure 7-13 however. To satisfy the increased demand for fuel, the *injector* in the regulator opens, producing the irregular shape of fuel pressure record, with a minimum of -2.25 in. H_2O.

To conclude, the design differences among the three representative propane carburetion systems, reflected in the control of the fuel pressure, do not seem to have any particular influence on the economy. They do have importance however, during the transient regimes of the engine, determing the speed of response and the drivability (e.g.: with the BEAM system, the engine responds very fast to changes in speed and load). For the average fuel economy, it was shown in Chapter 5 the main importance of the system's ability to provide the right air-fuel mixture as a function of load, avoiding the high exhaust temperature region around stoichiometric.

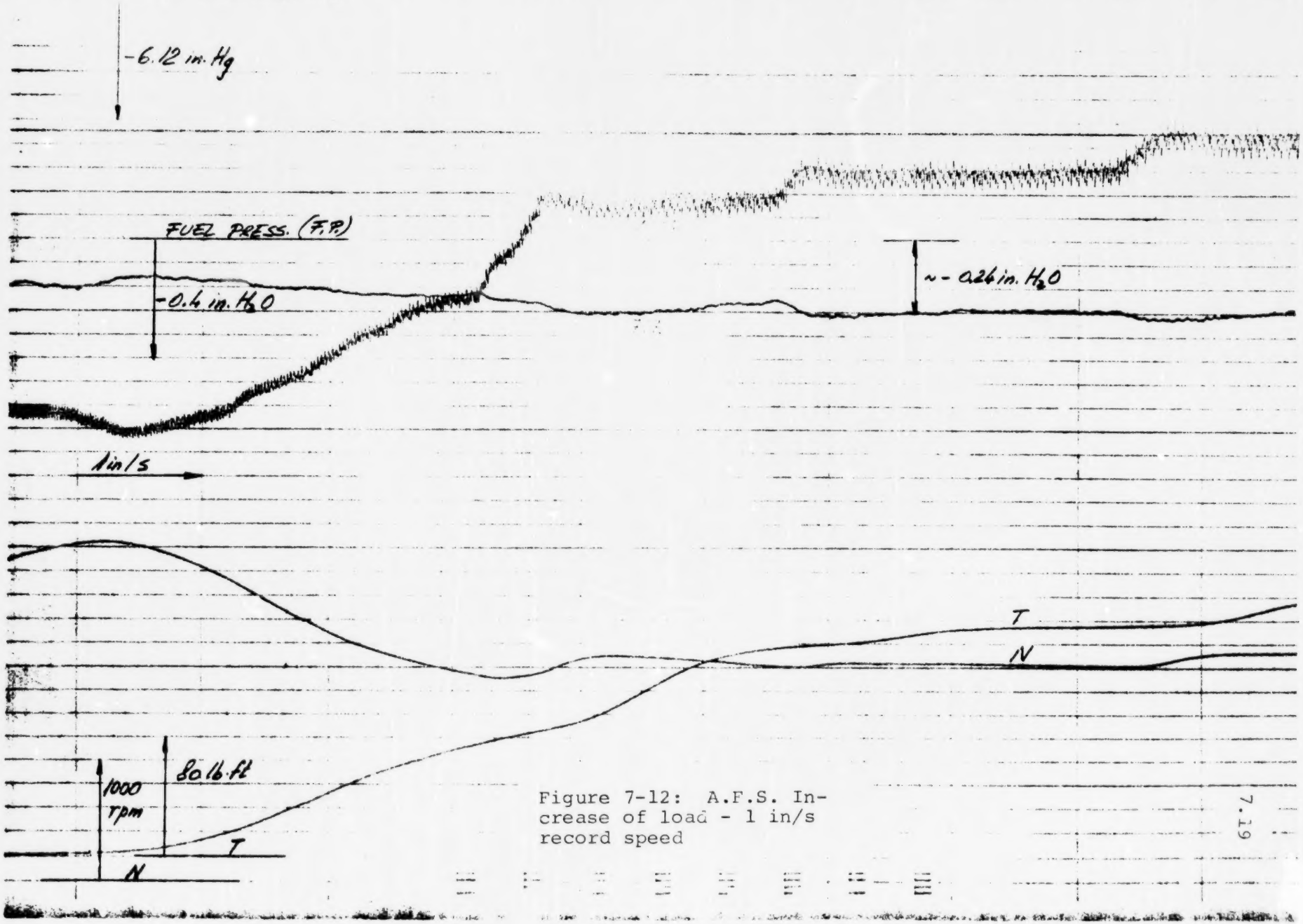


Figure 7-12: A.F.S. Increase of load - 1 in/s record speed

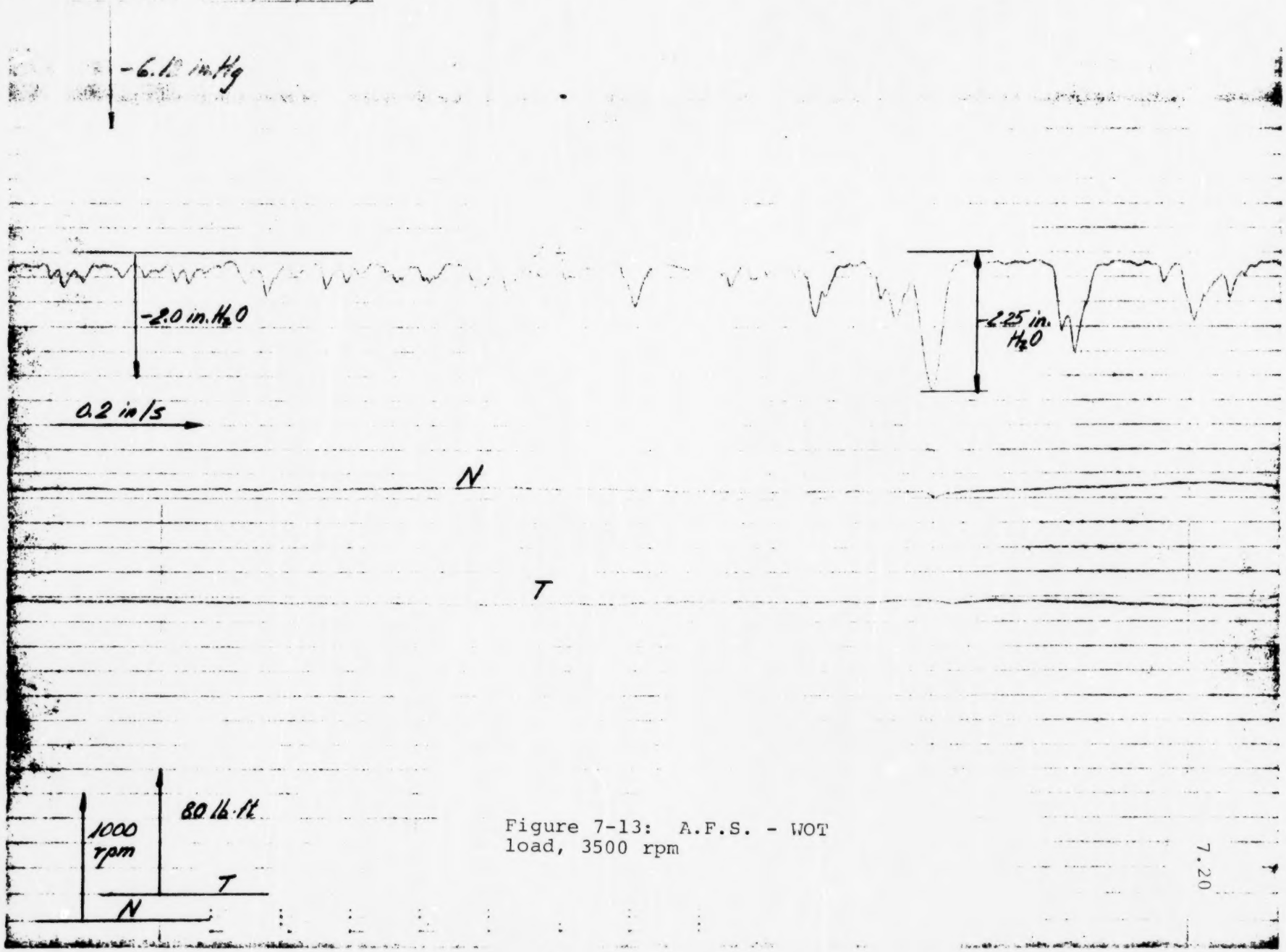


Figure 7-13: A.F.S. - WOT load, 3500 rpm

8. CONCLUSIONS

8.1 The maximum power developed at wide open throttle using propane carburetion is equal to the power developed with gasoline, if the air-fuel ratio is adequate (approximately 0.93 to 0.95 equivalence ratio).

8.2 The energy efficiency of the propane systems tested is higher by 2.4 to 15.6% on average, compared to gasoline. For the best systems the efficiency is higher by 3.8 to 17.8%, depending on load.

8.3 The increase in volumetric consumption with propane averages between 16.4 and 35.1% depending on load, with an overall average of 24.5%.

8.4 The commercial spark advance calibration used at the present time, with 12 to 14^{o} initial timing, and a maximum of 30 to 32^{o} without vacuum advance is acceptable as a first approximation, yielding fair fuel economy and exhaust temperatures.

8.5 Further improvements of energy efficiency up to 9.1% at partial loads was achieved by optimization of timing and air-fuel ratio (1.25 to 1.40 equivalence ratio) for this particular model of engine.

8.6 To implement in a practical way the optimum values established, the distributor must be modified (centrifugal and vacuum advances) and the propane carburetion systems calibrated for the equivalence ratio indicated in 8.1 and 8.5.

8.7 The exhaust gas temperatures for gasoline and propane are comparable, with the values higher for gasoline at low speeds and for propane at maximum speed. The values are influenced by the proximity to stoichiometric air-fuel mixture and timing.

8.8 The levels of HC and CO emissions are generally lower for propane. NO emissions is far higher with propane, in the absence of the exhaust gas recirculation control system.

8.9 The propane carburetion systems tested in this program are of a more constant quality than some equipment used in the former project, providing a better grouping of results.

APPENDIX 1

Calculations for Corrected Parameters

$$bp_t\ [hp] = \frac{T_t[lb.\ ft.] \cdot N_t[rpm]}{5252} \qquad (1)$$

bp_t = brake power; observed at test conditions

T = torque

N = speed

5252 = G, power constant

$$bmep_t\ \left[\frac{lb.}{in^2}\right] = \frac{396{,}000 \times 2}{300 \cdot N_t\ [rpm]}\ bp_t\ [hp] = 2640\ \frac{bp_t\ [hp]}{N_t\ [rpm]} \qquad (2)$$

bmep = brake mean effective pressure

396,000 = E, units of work conversion factor

2 = a, engine revolutions per cycle

300 = D, engine displacement [in^3]

$$fp_t\ [hp] = bp_t\ [hp]\ \left(\frac{100}{n[\%]} - 1\right) \qquad (3)$$

fp_t = friction power; observed

n = mechanical efficiency - see table 1 in SAE J816 b, at different bmep and rpm

$$F_t\ [lb./h] = W_t\ [lb.] \cdot \frac{60}{M[min]} \qquad (4)$$

F = fuel consumption

W = mass of fuel

M = time of fuel measurement

$$bsfc_t\ [lb/hp.h] = \frac{F_t[lb/h]}{bp_t\ [hp]} \qquad (5)$$

bsfc = brake specific fuel consumption

$$B_d[in\ Hg] = B[in\ Hg] - e[in\ Hg] \qquad (6)$$

B_d = barometric pressure - dry air conditions

e = water vapour pressure in atmosphere (see chart for wet-dry bulb temp.)

$$C_s = \frac{29.00\ [in\ Hg]}{B_{dt}\ [in\ Hg]} \cdot \left(\frac{t_t\ [°F] + 460\ [°F]}{85\ [°F] + 460\ [°F]}\right)^{0.5} \qquad (7)$$

C_s = correction factor, for standard atmospheric conditions

29.00 = B_d*, standard ambient dry barametric pressure

B_{dt} = barametric pressure - observed

t_t = ambient temperature - observed

460 = A, correction for absolute temperature

85 = t*, standard ambient temperature

$$bp_c\ [hp] = (bp_t\ [hp] + fp_t\ [hp])\ C_s - fp_t\ [hp] \qquad (8)$$

C = corrected to standard conditions

$$T_c = \frac{5252}{N_t\ [rpm]} \cdot bp_c\ [hp] \qquad (9)$$

$$bmep_c = \frac{396{,}000 \times 2}{300.N_t\ [rpm]} \cdot bp_c\ [hp] = 2640\ \frac{bp_c\ [hp]}{N_t\ [rpm]} \qquad (10)$$

The relations (8) - (10) for a range of 28 ÷ 30 in Hg barometric pressure and 60 ÷ 110°F air inlet temperature.

APPENDIX 2

Calculation of Air-Fuel Ratio from Exhaust Gas Constituents [1,2,3]

The combustion reaction for a hydrocarbon fuel with air may be expressed as:

$$CHy + (n)O_2 + (3.76n)N_2 \rightarrow (a)CO_2 + (1-a-6c)\,CO + (b)H_2O + (c)C_6H_{14} + (d)NO + (\frac{y}{2} - b - 7c)H_2 + (n-a-\frac{1-a-6c}{2} - \frac{b}{2} - \frac{d}{2})O_2 + (3.76\,n - \frac{d}{2})N_2 \quad (1)$$

for one atom of carbon, in which:

( ) = mol of constituents for 1 mol of fuel CH_y (bracketed coefficient)

y = fuel atomic H/C ratio

C_6H_{14} = unburned hydrocarbon, reported as hexan

For a nondispersive infrared (NDIR) analyzer, the term (HC) can be multiplied by a factor of 1.8, to account for the lack of response to certain exhaust HC species (for flame ionization detectors - FID - the factor is 1.0).

Defining a "fuel conversion factor" N:

$$N = \frac{\text{mol exhaust}}{\text{mol fuel}} = \frac{100}{6(HC)+(CO)+(CO_2)} \quad (2)$$

( ) = molar percent (bracketed species)

expressed in [%], and summing the mols of products from eq. (1):

$$N = a+(1-a-6c)+w+c+d(\frac{y}{2}-b-7c)+(n-a-\frac{1-a-6c}{2}-\frac{b}{2}-\frac{d}{2})+(3.76\,n-\frac{d}{2}) \quad (3)$$

in which mols of water produced b are replaced by w, mols of water at analyzer, following any condensation. With no condensation, w = b.

$$N = 4.76\ n - 6c + \frac{1-a-6c-3b+y}{2} + w \qquad (4)$$

For the reactants in eq. (1):

$$\frac{\text{mol air}}{\text{mol fuel}} = n+3.76\ n = 4.76\ n \qquad (5)$$

combining eq. (4) and (5)

$$\frac{\text{mol air}}{\text{mol air}} = N+6c-\frac{1-a-6c}{2} + \frac{3b}{2} - \frac{y}{2} - w \qquad (6)$$

and because:

$$\frac{\text{mol X}}{\text{mol fuel}} = \frac{\text{mol X}}{\text{mol exhaust}} \cdot \frac{\text{mol exhaust}}{\text{mol fuel}} = \frac{(X)}{100} \cdot N \qquad (7)$$

Eq. (6) becomes:

$$\frac{\text{mol air}}{\text{mol fuel}} = N+\frac{6(HC)}{100}\cdot N-\frac{(CO)}{200}\cdot N+\frac{3(H_2O)}{200}\ N- - \frac{y}{2} - \frac{(H_2O)a}{100}\cdot N \qquad (8)$$

where $(H_2O)_a$ is water concentration (percent) at analyzers

$$\frac{A}{F} = \frac{\text{g air}}{\text{g fuel}} = \frac{\text{mol air}}{\text{mol fuel}} \cdot \frac{\text{M air}}{\text{M fuel}} \qquad (9)$$

where M refers to molecular weight

$$\frac{A}{F} = \frac{\text{M air}}{\text{M fuel}}\left\{N + \frac{N}{100}\left[6(HC) - \frac{(CO)}{2} + \frac{3(H_2O)}{2} - (H_2O)_a\right] - \frac{y}{2}\right\} \qquad (10)$$

Assuming a fixed value for the water-gas equilibrium

$$k = \frac{(CO)(H2O)}{(CO_2)(H_2)} = 3.8 \qquad (11)$$

and with

$$(H_2) = (\frac{y}{2} - b - 7c)\ \frac{100}{N} = \frac{y}{2}.\frac{100}{N} - (H_2O) - 7\ (HC) \qquad (12)$$

$$(H_2O) = \frac{\frac{y}{2}.\frac{100}{N} - 7(HC)}{\frac{(CO)}{k(CO_2)} + 1} \qquad (13)$$

From eq. (10) and (13) a <u>carbon balance</u> air-fuel ratio can be expressed as:

$$\frac{A}{F} = \frac{M\ air}{M\ fuel}\left[\frac{100+6(HC)-\frac{(CO)}{2}+\frac{3(H_2O)}{2}-(H_2O)_a}{6(HC)+(CO)+(CO_2)} - \frac{y}{2}\right] \qquad (14)$$

in which:

$$(H_2O) = \frac{y[(CO_2)+(CO)]}{2\left[\frac{(CO)}{3.8(CO_2)}+1\right]} \qquad (15)$$

Molecular weights:

M air = 28.96

M fuel = Mc + y M_H = 12.01 + 1.008 y

An <u>oxygen balance</u> independent of the amount of water and diluents is also derived:

$$n = a + \frac{1-a-6c}{2} + \frac{b}{2} + \frac{d}{2} + (n-a-\frac{1-a-6c}{2} - \frac{b}{2} - \frac{d}{2}) \qquad (16)$$

$$n = \frac{N}{100}\left[(CO_2) + \frac{(CO)}{2} + \frac{(H_2O)}{2} + \frac{(NO)}{2} + (O_2)\right] \qquad (17)$$

$$\frac{A}{F} = 4.76\ n\ \frac{M\ air}{M\ fuel} \qquad (18)$$

$$\frac{A}{F} = 4.76 \frac{M\ air}{M\ fuel} \frac{N}{100} \left[(CO_2) + \frac{(CO)}{2} + \frac{(H_2O)}{2} + \frac{(NO)}{2} + (O_2)\right] \qquad (19)$$

or

$$\frac{A}{F} = 4.76 \frac{M\ air}{M\ fuel} \left[\frac{(CO_2)+\frac{(CO)}{2}+\frac{(H_2O)}{2}+\frac{(NO)}{2}+(O_2)}{6(HC) + (CO) + (CO_2)}\right] \qquad (20)$$

In equations (14) or (20), the molar concentration (HC) is multiplied by 1.8 if the analyzer is nondispersive infrared.

The oxygen balance computation of A/F ratio for 31 samples of exhaust analysis quoted in Table A-1 of Reference [1], resulted in an average error of +0.2352 comparative to measured values of air and fuel mass flows.

For propane (C_3H_8):

$y = \frac{H}{C} = \frac{8}{3} = 2.6667$ and M fuel = $12.01 + 1.008 \times 2.6667 = 14.698$

The values in Chapter 5 are calculated according to eq. (20) and (15).

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3. GM Test Code, VI Edition, 1975, pp. 170; "Air-Fuel Ratio Determination from Exhaust Gas Constituents".